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Macroeconomic evaluation of EU R&I Policies : ways and Means

Pierre Le Mouël

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Pierre Le Mouël. Macroeconomic evaluation of EU R&I Policies : ways and Means. Economics and Finance. COMUE Université Côte d'Azur (2015 - 2019), 2019. English. NNT : 2019AZUR0008 . tel-02497667

HAL Id: tel-02497667

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THÈSE DE DOCTORAT

L'évaluation Macroéconomique des Politiques de R&I de l'UE : L'Art et la Manière

Pierre LE MOUËL

Laboratoire GREDEG

**Présentée en vue de l'obtention
du grade de docteur en sciences économiques
d'Université Côte d'Azur**

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Soutenu le : 29 novembre 2019

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Macroeconomic Evaluation of EU R&I

Policies: Ways and Means

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Titre : L'Évaluation Macroéconomique des Politiques de R&I de l'UE : L'Art et la Manière

Résumé : Cette thèse de doctorat décrit les mécanismes de R&I que les modèles macroéconomiques QUEST III, NEMESIS et RHOMOLO intègrent, et comment ces modèles sont utilisés pour évaluer les politiques de R&I qui sont introduites par la Direction Générale de la R&I de la Commission Européenne.

QUEST III, NEMESIS et RHOMOLO sont des modèles appartenant à différentes traditions économiques, avec également différents niveaux de détail. QUEST est un modèle d'Équilibre Général Dynamique Stochastique (DSGE), le plus en accord avec les canons de la théorie macro-économique moderne. Il y a un modèle pour chacun des pays de l'UE(28), avec des fondements micro-économiques dérivés explicitement de la maximisation intertemporelle des profits et de l'utilité sous l'hypothèse d'anticipations parfaites. NEMESIS est comme QUEST, un modèle pour chacun des pays de l'UE, mais les deux modèles diffèrent profondément dans leur approche des phénomènes économiques. NEMESIS est un modèle macro-sectoriel (30 secteurs), d'inspiration néo-keynésienne, avec des coûts d'ajustement, des anticipations adaptatives, des prix rigides, et des taux de change et d'intérêt exogènes, qui ne permettent pas au modèle de décrire un équilibre général, même dans le long terme. RHOMOLO, qui est un modèle d'économie spatiale basé sur les nouvelles théories de l'économie géographique, est le plus détaillé géographiquement, avec la modélisation en équilibre général de 267 régions européennes, avec leurs interactions. Le modèle comporte également une dimension sectorielle, les régions comportant chacune 10 secteurs d'activité. Comme pour NEMESIS, le grand niveau de détail de RHOMOLO, ne permet pas une résolution tournée vers l'avenir, et le modèle est résolu par une approche dynamique récursive.

En ce qui concerne la représentation de l'innovation, les trois modèles ont en commun de la faire reposer sur la forte évidence empirique, que les investissements en R&D ont été à l'origine des principales innovations technologiques, et progrès de productivité, dans les pays industrialisés au cours des dernières décennies. Du point de vue théorique, ils se réfèrent également tous, explicitement ou implicitement, aux nouvelles théories de la croissance, qui ont émergé à partir du début des années 1990. NEMESIS est certainement le modèle qui inclut les mécanismes de progrès technique les plus riches, avec notamment l'extension récente de ses mécanismes d'innovation au rôle joué par les investissements en TIC, en logiciels et en formation professionnelle, particulièrement importants pour représenter l'innovation dans les services. Mais les approches sectorielle, et "hors-de-l'équilibre" qui

sont suivies dans NEMESIS, n'assurent pas que le long-terme qui est décrit par le modèle, soit compatible avec la représentation de l'équilibre général au cœur du modèle QUEST. Dans QUEST, par contraste, le compromis est cette fois au prix de la richesse, et du degré de détail, des mécanismes d'innovation, qui sont restreints par les contraintes analytiques fortes, qu'imposent la modélisation DSGE. Pour RHOMOLO, à l'opposé, les limitations viennent davantage des contraintes de données, et de la difficulté de représenter certains phénomènes, comme les externalités de connaissance, avec un niveau régional détaillé.

Si nous ajoutons à ces différences dans la structure des modèles, la représentation de la croissance endogène, versus semi-endogène, que les modèles supportent, nous ne pouvons certainement pas espérer qu'ils fournissent des résultats similaires lorsqu'ils sont utilisés pour l'évaluation des politiques de R&I de l'UE, mais tout au moins que leurs résultats se complètent utilement. Il y a l'art, et la manière, pour l'évaluation macroéconomique des politiques de R&I de l'UE, et c'est à la présentation de ce "compromis" que forment les différents modèles, à partir de l'analyse des principaux travaux théoriques qui se sont développés, depuis les années 1950, que cette thèse est dédiée.

Mots-clé : Croissance endogène, Croissance multisectorielle, Changement technologique, Productivité agrégée, Comptabilité de la croissance, Innovation de produit et de procédé, Innovation dans les services, Recherche publique et privée, R&D, TIC, Intangibles, Externalités de connaissance, Modélisation macroéconomique, Modèles de simulation de grande taille, CGE, Modèles néo-keynésiens, DSGE, Politiques de R&I, Subventions à la R&I, Évaluation des politiques de R&I

Codes JEL : E170, O410, O470, O310, O320, O330, O380, O410, O470, D580, E120, E130, E170

Title: Macroeconomic Evaluation of EU R&I policies: Ways and Means

Summary: This PhD thesis describes the R&I mechanisms that the macroeconomic models QUEST III, NEMESIS and RHOMOLO incorporate, and how these models are used to evaluate the R&I policies that are introduced and monitored by the General Directorate for R&I of the EC.

QUEST III, NEMESIS and RHOMOLO are models belonging to different economic traditions, and also possess different levels of detail. QUEST is a macroeconomic Dynamic Stochastic General Equilibrium (DSGE) model, the most in line with modern macroeconomic theory. There is one model for every EU(28) country, with microeconomic foundations explicitly derived from inter-temporal profit and utility maximization under perfect foresight, as in the general equilibrium setting of modern theoretical models of economic growth. NEMESIS is, like QUEST, a model for every EU(28) country, but the two models are very different in their modeling approach. NEMESIS is a macro-sectorial model (30 sectors) of neo-Keynesian inspiration. There are adjustment costs, adaptive expectations, wage rigidities and exogenous exchange and interest rates, which prevent the model from describing a general equilibrium, even in the long-run. RHOMOLO, is a spatial model based on the new economic geography theories and is the most detailed geographically, as it describes the general equilibrium modeling of 267 EU regional economies and their interactions. This model also has a sectorial dimension and each region contains 10 economic sectors. Like NEMESIS, the great level of detail in RHOMOLO, prevents any forward-looking dynamics, and both models are solved according to a recursively dynamic approach.

For modeling innovation, what the three models have in common is that they were inspired by the strong empirical evidence that investments in R&D were at the origin of major technological innovations and TFP growth in advanced industrialized countries over the past decades. On the theoretical side, they all also refer, explicitly or implicitly, to the New Growth Theories that have emerged from the beginning of the 1990s. NEMESIS, that is grounded on empirics, is certainly the model that includes the richest mechanisms of technical change, with, notably, the recent extension of the innovation mechanisms of the model to the role played by investments in ICT, software and professional training, that are particularly important when representing innovation in the service sectors. But the sectorial and “out-of-equilibrium” approaches that are used in NEMESIS, do not ensure that the long-run behavior of the model will conform to the general equilibrium prerequisite present in QUEST III. For QUEST III, in contrast, this time the compromise is at the cost of the richness and the level of detail of the innovation mechanisms of the model, that are restricted by the forward-looking expectations,

and the high theoretical constraints, that DSGE modeling imposes. For RHOMOLO, on the contrary, the limitations come more often from the data constraints and the difficulty in representing certain phenomena, such as knowledge externalities, on a detailed regional level.

If, to these differences in the structure of the models, we add the endogenous, versus, semi-endogenous representation of growth they support, we could certainly not expect that they would provide similar results when evaluating EU R&I policies, but at least that their results would usefully complement each other's. There are various ways and means, for the macroeconomic evaluation of EU R&I policies, and this thesis is dedicated to the presentation of this "compromise" the different models form, using the analysis of the main findings in the empirical and theoretical works developed since the fifties, to measure and represent economic growth.

Key-words: Endogenous Growth, Multi-sector Growth, Technological Change, Aggregate Productivity, Growth Accounting, Product and Process Innovation, Service Innovation, Private and Public Research, R&D, ICT, Intangibles, International Technology Diffusion, Knowledge Spillovers, Macro-Econometric Modeling, CGE, Neo-Keynesian Models, DSGE, Large-Scale Simulation Models, R&I Policy, R&I Subsidies, R&I Policy Evaluation

JEL codes: E170, O410, O470, O310, O320, O330, O380, O410, O470, D580, E120, E130, E170

Thanks

This thesis could not be written without the help and the support of the people and institutions I would like to thank here.

First the Université Côte d'Azur that accepted my candidature for this PhD and allowed me to highlight more than twenty years of research with the delivery of this thesis. Particular thanks go to the GREDEG laboratory, and the DESPEG doctoral school that both accepted me as a member. In Nice, I would like to thank Elisabeth Gazano, Isabelle Arfeuille, Ghislain Chave, Martine Naulet and Jeanne Scheit for their administrative support, and Jean-Luc Gaffard, my thesis Director, as well as Jean-Pierre Allegret, Patrick Musso, Flora Bellone, Olivier Bruno and Lionel Nesta, for their academic support.

Second, the services of the Directorate General For Research and Innovation of the European Commission, that financially supported much of the research presented in this dissertation, beginning with the financing of the NEMESIS model from 2000 onwards. This was the start of a fascinating adventure and of an intense collaboration that continues today. In Brussels, I would like to thank François Valette, Daniel Debey, Domenico Rosetti Di Valdalbero, Hugur Muldur, Henri Delanghe, Marco Grancagnolo, Liviu Stirbat and Julien Ravet.

Third the ERASME laboratory, formerly at the École Centrale de Paris, and now at SEURECO, where I have my oldest and today closest collaborators. In Paris, I thank Paul Zagamé, who guided me in this difficult task of applied macro modeling, Arnaud Fougeyrollas, who was the main artisan of the NEMESIS model, as well as Baptiste Boitier, Gilles Koléda and Boris Le Hir: those who collaborated the most with me and who supported my work in various other ways.

Fourth, the thesis committee, Jean-Luc Gaffard, Michele Cincera, Pierre Mohnen, Patrick Sevestre, Lionel Nesta and Paul Zagamé, for accepting to be part of this adventure, and for evaluating this thesis.

Fifth Georgina, who helped me with my English.

Then finally my family, my son Rémi and his mum Shu-Wen, my brother and sisters, Jean-Patrick, Pascale and Bénédicte, my parents, Gilbert and Giselle, and all my friends too many to be named as I would not like to forget anyone.

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¹This section builds partly on Le Hir (2012, [205]) concerning the presentation of the concept of GPT, as does the paper by Le Mouël, Le Hir, Fougeyrollas, Zagamé and Boitier (2016 [209]).

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²This section builds on the works Verspagen *et al.* (2017a, [328], and 2017b, [329]) on the I3U project, I3U deliverable D9.4 ([169]), and on the I3U policy brief of September 2018 ([168]) “*The State of the Innovation and the working of the European Innovation Systems*”.

³The content in this section is mainly based on the I3U policy brief of September 2018, [168]).

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Chapter 1

General Introduction

1.1 Context of the research

At the end of the 1990s, the general feeling was that it was the beginning of the “third industrial revolution”. The fast development of internet and of ICT technologies, started to produce important positive effects on the growth rate of factor productivity, after two decades of weak and sluggish evolution.

But scrutinizing this, it was fast evident, from the comparison with the United States, that Europe was lagging far behind in terms of both ICT production and adoption, with reduced impacts on productivity. To take some examples (see Brécard *et al.*, 2004, [41], page 10), from OECD data, in 1999 the ICT sector was about two times more developed in the US (4.5% of GDP) than in the EU (2.4%), and the share of ICT investment was about a third of Gross Fixed Capital Formation (GFCF) in the US, against only a sixth in countries such as France or Germany. Comparing the 1980s with the 1990s, the Total Factor Productivity (TFP) revival was about 0.5% in the US between the two periods, while in most European countries, productivity continued to fall. In the case of the US, the highly developed ICT sector permitted growth in productivity in ICT producer sectors. The transformation of the links between firms and customers, from the development of internet and large investment in ICT devices, also provoked strong productivity gains in ICT user sectors. This led to rationalization of production processes and the reduction of transaction costs. It contrasts with the situation in the EU countries, where, despite noticeable exceptions, such as Sweden, Norway, Denmark and Finland, these gains could not materialize.

This evidence that the EU was “missing” the train in this third industrial revolution, and could not fully benefit fully from this virtuous circle between R&D investments, innovations, new technologies and productivity growth, therefore convinced the heads of states and governments of the EU, at the European Council of Lisbon in March 2000, to set a new strategic goal for Europe, “(…) to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion” (European Parliament, 2000, [261]).

With the additional observation that R&D research intensity had declined during the last decade; while it had increased sharply in the US and in Japan, to reach close 3% of GDP in 2000 against only 2% in Europe; the Barcelona Council of March 2002 introduced this central element in the strategy “(…) that overall spending on R&D and innovation in the Union should be increased with the aim of approaching 3% of GDP by 2010” (European Commission, 2002, [?]).

To investigate the potential positive socioeconomic and environmental impacts that the EU could

benefit from reaching this 3% R&D target in 2010, the Directorate General for Research and Innovation (DG RTD) of the European Commission (EC), requested, in 2003, a macroeconomic evaluation of the Barcelona objective. This study (see Brécard *et al.*, 2004, [41], and 2006, [40]) was made using the NEMESIS model (New Econometric Model for Evaluation by Sectoral Interdependencies and Supply) that was developed by a research consortium led by the laboratory ERASME (Équipe de Recherche en Analyse des Systèmes et Modélisation Économique), belonging to the École Centrale de Paris, and the University of Paris-I-Panthéon-Sorbonne, in France.

The NEMESIS model was built between 2000 and 2002 using funding from the European Commission 5th Framework programme (FP) for R&I. Historically, together with the model GEM-E3 that is managed by the National Technical University of Athens (NTUA), it was the first detailed macroeconomic model for the EU economy integrating an endogenous representation of R&I, that could be used for the evaluation of EU R&I policies.

While GEM-E3 became progressively specialized, by the university of Athens, in the representation of energy technologies, NEMESIS continued to deepen the representation of innovation in every production sector, and was regularly used for the ex-ante, interim and ex-post evaluation of the EC Framework Programmes (FP) for R&I, that are the main instrument of the EU R&I strategy. We can quote for example, in 2005, the ex-ante evaluation of the 7th FP (EC, 2005, [69]; Delanghe and Muldur, 2007, [98]), that covered the period 2007 to 2013; in 2012, the ex-ante impact assessment of the current programme (EC, 2012 – Annex 5, [115]), Horizon 2020 (2014-2020); in 2017, the ex-post evaluation of FP7, and interim evaluation of Horizon 2020 (PPMI, 2017, [272]; EC, 2017, [71]).

Though NEMESIS acquired this long track record for the evaluation of EC R&I programmes, it was fast evident that the model had its own limitations and could not answer all the questions. There was also a need to diversify the expertise, and develop, or adapt, other models for the specific task of the evaluation of EU R&I policies. There were two others models available for that. The first is the model QUEST III, developed and used by the Directorate General for Economic and Financial Affairs (DG ECFIN), where R&I mechanisms were introduced in the mid-2000s (see Roeger *et alii*, 2008 [281]). The second was the model RHOMOLO (Regional Holistic Model), that was developed from 2010 by the Directorate General Joint Research Center (DG JRC), in collaboration with the Directorate General for Regional and Urban Policy (DG REGIO), with a version of the model including R&I mechanisms that recently became available (Lecca and Sakkas, 2018, [212]). Then, for the first time in 2018, QUEST and RHOMOLO were used for the assessment of EC framework programmes, with, in 2018,

the ex-ante evaluation of the next programme, Horizon Europe, that was made in complement to the in-depth analysis that was performed with the NEMESIS model (EC, 2018, [72], and Boitier *et al.*, 2018, [34]).

1.2 Subject of the thesis

The subject of this PhD thesis is to describe, as accurately as possible, the R&I mechanisms that NEMESIS, QUEST III and RHOMOLO incorporate, and how the models are used to evaluate the research policies that are introduced and monitored by the General Directorate for R&I (DG RTD) of the EC¹.

QUEST III, NEMESIS and RHOMOLO are models belonging to different economic traditions, with different levels of aggregation:

QUEST is a macroeconomic Dynamic Stochastic General Equilibrium (DSGE) model, the most in line with the modern macroeconomic theory. There is one model for every EU(28) country, with microeconomic foundations explicitly derived from inter-temporal profit and utility maximization under perfect foresight, that mimics the main features of the general equilibrium setting of the recent theoretical models of economic growth.

NEMESIS is, as QUEST, a model for every EU(28) country, but the two models differ deeply in their modeling approach. NEMESIS is a macro-sectorial model (30 sectors) using neo-Keynesian inspiration. There are adjustment costs, adaptive expectations, wage rigidities and exogenous exchange and interest rates, which prevent the model from describing a general equilibrium, even in the long-run. The macroeconomic track in NEMESIS, is the resultant of bottom-up dynamics from the interaction between very heterogeneous production sectors, and pure macroeconomic forces, such as the influence of the household and public sectors.

RHOMOLO is a spatial model based on the new economic geography theories. It is more detailed geographically, using the general equilibrium modeling of 267 EU regional economies and their interactions. The model has also a sectorial dimension, each region containing 10 economic sectors. Like for

¹We have limited the focus, in this thesis, to NEMESIS, QUEST III and RHOMOLO, while, at the initiative of the DG RTD, other models are currently being developed for the analysis of the EU R&I policies, in the context of H2020 research projects FRAME and MONROE. The reason is that, when writing these lines, we did not have any reliable documentation on the R&I mechanisms that these will incorporate. We do not present GEM-E3 either, as the scope of this model is limited to energy technologies, that refer to different concepts and mechanisms, than those that are at the core of the NEMESIS, QUEST III and RHOMOLO models.

NEMESIS, the huge scope of RHOMOLO, prevents any forward-looking dynamic, and both models are solved according to a recursively dynamic approach.

Concerning the modeling of innovation, what the three models have in common is that they were inspired by the strong empirical evidence, that investment in R&D was at the origin of major technological innovations, and TFP growth, in advanced industrialized countries over the past decades. On the theoretical side, they all refer also, explicitly or implicitly, to the New Growth Theories (NGT) that emerged from the beginning on the 1990s, with the seminal papers of Romer (1990, [284]), Grossman and Helpmann (1991, [152]), and Aghion and Howitt (1992, [4]). These NGT, echoing the main results of the abundant econometric literature on the link between R&D and productivity, insist on three main points. Firstly, technological innovation results from investments made by profit-seeking firms, motivated by the creation of monopoly rents. Secondly, inter-temporal R&D knowledge externalities, either intra-sectorial or inter-sectorial, national or international, are at the source of increasing returns. This allows them to fight against the law of diminishing returns, like the exogenous technical progress in the previous neoclassical model of economic growth introduced by Solow (1956, [300]) and Swan (1956, [306]). Thirdly, market failures produced by knowledge externalities, and the risky nature of R&I activities, mean that firms will tend, spontaneously, to under-invest in R&D, compared to the social optimum, which reinstates the role of public policy in the area of R&I.

The representation of innovation, in the three models, differs, however, depending on the way they take into account the three points above:

In QUEST III, investments in R&D provide firms with monopoly rents from the invention of new varieties of capital goods, that improve the total factor productivity in the final good sector. Therefore innovations act in the model as process innovations, similarly to the theoretical model proposed by Jones in 1995 (Jones, 1995b, [180]), that was adapted to the multi-country structure of QUEST III, with notably the introduction of international knowledge spillovers between EU countries. The particularity of the representation of innovation in QUEST III is that, following the terminology proposed by Jones, the long-run growth rate of GDP per capita is semi-endogenous. It results from investment in R&D by firms, and from that point of view it is endogenous, but its long-run growth rate cannot be influenced by public policy instruments, such as R&D subsidies or tax credits, that only have temporary effects, and therefore only influence the level of GDP, and not its growth rate.

The situation is different in NEMESIS, where it is assumed, alternatively, that the long-run growth rate of GDP per capita is “fully endogenous”, and can be influenced by policy instruments. The

representation of innovation in the model does not refer explicitly to the NGT literature, but the long-run growth process in the model is similar to the second generation of “fully endogenous” growth models, that have developed in parallel to the semi-endogenous growth approach initiated by Jones, with the seminal contributions of Young (1998, [335]), Aghion and Howitt (1998, [8]), Dinopoulos and Thomson (1998, [101]) and Howitt (1999 [165]). A second important difference between NEMESIS and QUEST III, in the representation of innovation, is that in NEMESIS, investments in R&D result in two types of innovation: there are process innovations that increase TFP, like in QUEST III, but also product innovations that raise the average quality of products. The presence of product innovation in the model is very important, as the econometric literature generally describes higher output and employment impacts for product, than for process innovations. The sectorial dimension of NEMESIS permits the representation of the exchange of knowledge, and the transfer of productivity surplus between production sectors, and between countries, that cause many channels of structural change in the model, where all the sectors, and all the countries, do not grow at the same rate.

In RHOMOLO, the modeling of innovation is still not as developed as in QUEST III and NEMESIS. The R&I decision of firms is not modeled, and it is assumed that TFP, in the different sectors and regions, grows proportionally to the R&D stocks accumulated from exogenous public and private investments. Innovations are therefore, as in QUEST III, process innovations only. Concerning knowledge externalities, there is no inter-regional or inter-national dimension, but there are externalities between sectors, as it is the pool of all private and public R&D investments, that drives the TFP growth in the different sectors. This modeling of knowledge externalities remains, however, quite rudimentary. Finally, even if the R&D decision was endogenous in RHOMOLO, as in QUEST III, the long-run growth rate of output per capita could not be influenced by policy instruments in the model, because of the linear relationship it has between the growth rates of TFP, and the growth rate of R&D stocks. The representation of technical change in RHOMOLO therefore also belongs also to the semi-endogenous growth family.

We could finally say, from this succinct introduction to the three models, that “*Applied macro modeling is the art of the compromise*”, or, in the words of Blanchard, “*No model can be all things to all peoples*” (2017, [31]).

NEMESIS, that is grounded on empirics, is certainly the model that includes the richest mechanisms of technical change, when compared to the empirical literature, with both process and product innovations. There is also the recent extension of the innovation mechanisms of the model to the

role played by investments in ICTs, software and professional training, that are particularly important when representing innovation in the service sectors. The model also includes, with the various economic activities it represents, many channels of structural change resulting from investments in R&I, such as the reallocation of the labor force in the more progressive sectors. But the sectorial, and “out-of-equilibrium” approach (2014, [13]) that is followed in NEMESIS, does not ensure that the long-run behavior of the model will conform to general equilibrium prerequisite present in QUEST III, in the image of the modern theories of economic growth.

By contrast, for QUEST III, the “compromise” is at the cost of the wealth of detail of the innovation mechanisms, that are restricted by forward-looking expectations, and high theoretical constraints, that imposes the DSGE modeling.

For RHOMOLO, though, the limitations come more from data constraints, and the difficulty in representing certain phenomena, such as knowledge externalities, at a detailed regional level. But RHOMOLO should, *a priori*, be a very appropriate tool for analyzing, for example, the impact of the share of European Structural and Investment (ESI) funds financing R&I and human capital.

If we add to these differences in the structure of the models, the endogenous, versus, semi-endogenous representation of growth they support, we could certainly not expect that they would provide similar results when evaluating EU R&I policies, but at least that their result would complement each other’s usefully. Therefore this thesis is dedicated to the presentation of the “*compromise*” that each of these models represents.

1.3 Organization of the thesis

This thesis is organized in three parts with two chapters each.

The first part, “*The Facts and the Theories*”, exposes the main findings of the empirical and theoretical works developed, from the fifties, to measure and represent economic growth, with a focus on the role played by R&D investment and its externalities.

On the empirical side, the second chapter, “*The Econometric Literature on R&D*”, presents the principal concepts and results of the applied literature on R&D: The output elasticities and private rates of return from R&D, R&D spillovers and social returns from R&D, the role of public R&D and the importance of having a sufficient “*absorptive capacity*” of external research.

On the theoretical side, chapter 3, “*The New Growth Theories*”, illustrates how the neoclassical

Chapter 1. General Introduction

model of growth was progressively adapted to endogenize economic growth, with the introduction of monopolistic competition based on R&I investment by profit seeking firms, and the central role played, in that process, by inter-temporal knowledge spillovers.

The second part, *“The Macro Models Used by the European Commission”*, introduces the macro simulation models that are used by the European Commission for the evaluation of EU R&I policies.

Chapter 4, *“The Endogenization of Innovation on R&D”*, shows how innovation is endogenized in the three Macro models that are currently available. These belong to different economic traditions, with QUEST, that is DSGE, NEMESIS, that is macro-econometric, and RHOMOLO, that is a spatial CGE model. To illustrate this, a comparison of the evaluation by the three models of the next EC Framework Programme for R&I, Horizon Europe, is also proposed.

Chapter 5, *“Beyond R&D: A new Frame for NEMESIS”*, describes a recent improvement on the innovation mechanisms of NEMESIS, with the concept of ICT as GPT, that was first proposed by Bresnahan and Trajtenberg in 1995 ([43]). It extends the conceptual framework to the role played by investment in ICT and in other intangibles and not just R&D (Training and software), of particular importance for innovation in service sectors.

Finally the third part, *“The Evaluation of EU R&I Policies with NEMESIS”*, presents the results of recent EU R&I policy evaluation with the NEMESIS model.

Chapter 6, *“H2020 Interim Evaluation”*, details the methodology of the interim evaluation of the current EC R&I framework programme (PPMI, 2017, [272]; EC, 2017, [71]).

Chapter 7, *“Investigating the Impacts of Innovation Union (I3U)”*, enlarges the scope of policy with the results of the H2020 research project I3U², performed, between March 2015 and September 2018: an in-depth assessment of the 34 commitments of the Europe 2020’s Innovation Union flagship initiative (see European Commission, 2011, [70]), from three complementary approaches: the *“direct”* evaluation of the individual commitments by data mining and econometric techniques, a semi-quantitative application of the Innovation Systems theory, up to the Macro analysis of the NEMESIS model.

The reader can easily see, from this brief presentation of the organization of the thesis, that it progressively focuses on the case of NEMESIS. They are three main reasons for this:

The first, is that the author of this thesis was, from the beginning in 2000, working with Arnaud Fougeyrollas and Paul Zagamé, the main creators of the NEMESIS model, and of the endogenous

²See the I3U project website: <http://www.i3u-innovationunion.eu/>

growth mechanisms it incorporates. This PhD thesis is therefore also a way to highlight all the work that was achieved over this period of now nearly twenty years.

The second, is that the two other models, QUEST III and RHOMOLO, have begun only recently, with the case of Horizon Europe, to be applied to official evaluation of EU R&I policies. This has posed a limit to the possible illustrations of the results for these two models.

The third, is that the recent improvement of the innovation mechanisms of NEMESIS, that extends the range of innovation inputs to investments in ICTs and in other intangibles and not just R&D (Software and professional training), represents, in our opinion a very important development, that could be the subject of a full PhD dissertation. It is the first time that an applied detailed macro model includes such mechanisms. This extension of the model was achieved in a very tentative way, because of the lack of data, of empirics and of solid theoretical background, so must be used with these limitations in mind; it nevertheless considerably widens the range of innovation policies that the model could assess. A lot of innovation occurs today in the service sectors, and from the “*servitization*” of an increasing part of the industrial sectors, that we see in the emergence of the internet giants, and the case of the GAFAs. Therefore, this new version of the model appears to be better adapted to represent innovation in the service sectors, the transformation of the frontier between industry and services, and the specific increasing returns, and inter-temporal externalities, arising from the development of the broadband, and from the investments in ICTs and in a broader range of intangible assets, than R&D alone.

Part I

The Facts and the Theories

Chapter 2

The Econometric Literature on R&D

Chapter 2. The Econometric Literature on R&D

In this chapter we describe the main findings in the abundant econometric literature on R&D, innovation and productivity, that developed from the late 1950s, and that motivated the endogenous technical change modeling that was introduced in NEMESIS, and in other macro simulation models for the EU economy.

The objective is not to present an exhaustive survey, but to find the key features that should be present in macro simulation models, when endogenizing technical change and innovation. These features concern the size of the output and Total Factor Productivity (TFP) elasticities from R&D (in different industries and countries), the private and social rates of return from R&D, the role played by R&D spillovers, the impacts of private/public, basic/applied research, and the distinction between product and process innovations.

In the literature, R&D is generally used as a proxy for innovation, whereas R&D is only one input in the complex process leading to innovation, productivity and economic performance. The reason is that there is not much data on innovation inputs and outputs.

For example, data on ICT investment, that is an important driver for innovation in service industries, is still scarce, even if some progress has been achieved with databases such as EU-KLEMS ([309]). Recent databases, *e.g.* INTAN-Invest ([74]), also provide time series, beyond R&D, on other important innovation inputs such as software, training, design, new financial products, mineral exploration and artistic originals, advertising and organizational capital. Other data sources have developed that are increasingly used, such as the CIS surveys¹, but these data are qualitative or only semi-quantitative, and not well-suited for macroeconomic modeling, that is based on time series and data compatible with national accounting formats.

For innovation outputs, the situation is quite similar. There are few quantitative sources of information for measuring the different types of innovation² (*e.g.* new processes, new/improved products, organizational, ..) and the available data are nearly exclusively qualitative (from CIS and similar surveys). Patent data, that exist from over a century and at a very detailed technology level, can be used, as suggested originally by Giliches *et al.* (1986, ([149])) and by Griliches (1990, [143]), as good proxies for innovation output. But, if it works for technological innovations by industrial firms, it is less suitable for service industries where innovations are not patentable. Or the bulk of innovation, nowadays, occurs in service sectors, that represent about 80% of total value-added in OECD

¹See <https://cordis.europa.eu/news/rcn/10048/en>

²See OECD Oslo manual for a precise definition of innovation: <http://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm>.

countries. There are other limits to patent data, such as the fact that process and organizational innovation are generally not patentable. They consequently describe nearly exclusively product-type innovations. Furthermore, all industries do not have the same propensity to patent, which represents another limitation, for example for the purpose of inter-sectorial comparisons.

Despite these limitations, the literature on R&D and productivity has provided rich and diverse results on the way firms innovate, and on the economic performance of their innovations. While most of the studies are on manufacturing industries where R&D investment is concentrated, the methodologies developed also allow for the measurement of the impact of the technological innovations developed by industrial sectors in the user sectors. There are numerous ways to do that, for example by using inter-industrial transaction matrices as in Terleckyj (1974, 1980), or in Sakurai *et alii* (1996, [288]) in an international setting. For illustration, the latter show, for 10 OECD countries in the period 1970-1980, that “*While innovations are developed mainly in a cluster of high technology manufacturing industries, the main acquirers of technologically sophisticated machinery and equipment are a different cluster of industries in the service sector, with technology generation much more concentrated than technology use*”.

Starting from the presentation in Hall *et alii* ([155]), we first recall the general aim of the studies and present the first methodological issues, important for understanding and interpreting their results.

We then turn to the presentation of the key findings of the literature on the most investigated issues already evoked above, that are all central for the endogenization of technical change in macro models. They concern:

1. The size of the output and TFP elasticities resulting from R&D capital. If there exists “*excess*”- or “*above*” normal - returns from R&D capital, how large are they, *e.g.* compared to the returns of physical capital?
2. The contributions to productivity growth of the two kinds of R&D spillovers distinguished by Zvi Griliches (1979, [141]), the “*rent*” spillovers, occurring mainly from economic transactions between firms and countries, and the “*pure*” knowledge spillovers, coming from the accumulation of knowledge over time.
3. The social returns from R&D capital. How to measure them and how large are they?
4. The distinct impacts of public/private R&D, basic/applied research and process/product innovations.

2.1 Objectives and first methodological issues

Empirical literature measuring the contribution of technical progress to economic growth first appeared in the 1950s, with the development of coherent and harmonized systems of national accounts³. At that time, the development of the production theory and the introduction of the concepts of factors efficiency and total factor productivity, allowed the progress of growth accounting; then the Solow (1957 [301]) study, *“Technical change and the aggregate production function”*, proposed a first and theoretically well-grounded, empirical measurement of the contribution of technical change to economic growth.

In this breakthrough 1957 study, Solow showed that up to 87.5% of the growth of labor productivity in United States for the period 1909-1949 was attributable to exogenous technical change; but the development of accounting techniques, up to today, by introducing differentiated categories of capital and labor inputs, allow an important reduction in the measured contribution of exogenous technical change to productivity and economic growth. Dale Jorgenson, advocated in that direction (1996 [85]): *“(...) with ‘full’ measures of capital and labor inputs (...) exogenous productivity growth accounts only for 17 percent of growth”*.

The development of growth accounting, the main approach used for analyzing productivity growth up to the early 1970s, explained an increasing part of the Solow residual. It is still useful to assess the distinct contributions to productivity growth by the labor force composition, capital deepening and exogenous technical change. But it relies on an exogenous representation of growth, like in the Solow’s 1956 ([300]) seminal paper, and cannot provide a better understanding of the process of economic growth *per se*.

In parallel to the development of growth accounting techniques, theoretical and econometric studies tried to open the “black box” of the Solow residual. The main idea was that technical progress, that permitted the fight against the law of “diminishing returns” and acted as an engine of growth in the Solow (1956, *ibid*) model, was not “*mana from heaven*”, as Solow expressed himself in his 1957 paper: *“I am using the phrase ‘technical change’ as a shorthand expression for any kind of shift in the production function. Thus slowdowns, speed-ups, improvements in the education of the labor force, and all sorts of things will appear as ‘technical change.’”*. The general idea was that all the phenomena that could generate increasing returns and improve the productivity of economic resources participate in what was called “technical change”.

³Follow this link for a recap of the history of national accounting from the pioneering works of Richard Stones at the head of the the United Nations Statistical Commission (UNSC): <https://unstats.un.org/unsd/nationalaccount/hsna.asp>

On the empirical side, the evidence that investments in research by private firms, by government and by universities, are at the origin of the major technological innovations in advanced industrialized countries over the last decades, motivated the development of an abundant econometric literature, aiming to demonstrate the role played by R&D investments and R&D spillovers, in the process of technical change and economic growth.

The main empirical challenge was therefore, in complement to the the growth accounting framework, to “explain” the specific contribution of the growth of knowledge in the process of economic growth. For that, the general methodology that was adopted, from the early works of the late 1950s, was to link the Solow residual, as measured from growth accounting techniques, econometrically to the investments in research by private firms and by public research units. R&D data, that were fast available with a great level of detail⁴, were therefore used in these studies as a proxy for technological innovations at the origin of technological change and TFP growth.

2.1.1 The framework inherited from growth accounting literature

Most of the empirical studies on innovation and productivity start from Solow’s (1957, *ibid*) growth accounting framework, based on the production function. The general methodology used by these studies can be presented in a simplified manner by considering, in a first step, that the output is produced with a Cobb-Douglas production function involving an exogenous time trend, $e^{\theta_{ti} \cdot t}$, and a set of traditional production inputs, here:

1. Physical capital: K_{it} ,
2. and Labor: L_{it} .

We have therefore:

$$Y_{it} = A_i \cdot K_{it}^{\alpha_{ki}} \cdot L_{it}^{\alpha_{li}} \cdot e^{\theta_{ti} \cdot t} \quad (2.1.1)$$

where A_i is a scale parameter, θ_{ti} , α_{ki} , and α_{li} , are elasticity parameters and with, i and t respectively the firm (the industry or the country) and the time indexes⁵.

⁴From the successive versions of the OECD ANBERD (Analytical Business and Enterprise Research and Development) database, see: <http://www.oecd.org/sti/inno/anberdanalyticalbusinessenterpriseresearchanddevelopmentdatabase.htm>

⁵In practice, studies at aggregate of national level omit intermediate inputs, such as materials and energy, among production factors, as in Solow (1957). In this case, the measurement of output that is used is value-added or GDP; while it is production, when the intermediate inputs are introduced in the analysis.

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Taking equation 2.1.1 in natural logarithms leads to a linear expression for output, that can be estimated econometrically:

$$y_{it} = \alpha_{ki} \cdot k_{it} + \alpha_{li} \cdot l_{it} + \theta_{ti}. \quad (2.1.2)$$

with the small letters corresponding to the logarithms of the corresponding variables.

If we assume, as in growth accounting studies, that the returns to scale are constant and that all the factors are remunerated according to their marginal productivity, the elasticity parameters, α_{fi} , $f = k, l$ sum to 1 ($\sum_f \alpha_{fi} = 1$) and they all equal their factor share (\bar{s}_{fi}).

We can then construct an exact index for TFP growth, the Törnqvist index, such as, in logarithms:

$$\Delta \text{tfp}_{it} = \Delta y_{it} - \sum_f \bar{s}_{fi} \cdot \Delta f_{it}, \quad f = k, l \quad (2.1.3)$$

where, $\bar{s}_{fi} = \frac{s_{fit} + s_{fit-1}}{2}$, is the average value of factor f 's cost share between time $t-1$ and time t .

We combine 2.1.3 and 2.1.2 and assume that $\alpha_{fi} = \bar{s}_{fi}$, $f = k, l$, then the expression of the growth rate of productivity, that grows at the exogenous rate θ_{ti} , is as follows:

$$\Delta \text{tfp}_{it} = \theta_{ti} \quad (2.1.4)$$

From equation 2.1.4, the rate of growth of technical change can therefore be calculated as a (Solow) residual. But many problems emerge from this representation of technical change:

It assumes that the returns to scale are constant and that the factors are remunerated at their marginal cost. But, practically, there may exist scale economies and firms may use a mark-up pricing in the presence of imperfect competition. Furthermore, the TFP measurement can be biased by cyclical variations and changes in the utilization rate of production capacities.

In addition, the measurement of inputs and outputs is not simple. For example⁶, Jorgenson and Griliches (1967 [184]) have underlined the importance of distinguishing different categories of labor and capital inputs to better measure the Solow residual. The share of the work-force with higher skills (or higher educational attainment) increases in time, and if we do not control for this qualitative improvement of the labor (the accumulation of human capital), it pushes down the measurement of the labor input contribution to output growth. Thus it tends to overestimate the growth of the

⁶See Barro, 1998, and Jorgenson, 1996.

Solow residual. The measurement problems posed by capital input are similar. When the quality improvement of some capital input is miss-measured, such as ICT capital goods, it will push down the measurement of the capital input, and push up the Solow residual. And the reverse is true for the measurement of output: if we underestimate the quality improvement of output, it will push down both the measurement of output and that of the Solow residual.

Notwithstanding, the development of the growth accounting techniques, permitted a considerable reduction in the size of the Solow residual (as advocated by Jorgenson (1996, *ibid*) and already stressed above), leading to a reduction of the contribution of exogenous technical change from 87.5% in Solow (1957) to only 17% or so⁷. But there are still important limitations:

1. It is still based on very restrictive assumptions on economic conditions: Cobb-Douglas production functions with constant returns to scale, pure and perfect competitive behavior on input and output markets, profit-maximizing use of production factors, ...
2. It does not explain the causal relationships between the different variables and notably the determinants of TFP growth. It simply decomposes the growth of output between its different components.
3. It only refers to the production side of the economy, while a large part of innovations are motivated by consumption or demand side factors.

2.1.2 The framework used in econometric studies

The development of econometric studies can therefore be viewed as a response to these shortcomings in growth accounting literature.

Firstly, by econometrically estimating the output elasticities of the production function it is possible to relax the assumption of perfect competition and constant returns to scale. If there are increasing returns to scale, in equation 2.1.1, $\theta_i = \alpha_{ki} + \alpha_{li} > 1$, the TFP, or Solow residual growth, given previously by equation 2.1.4, can be re-expressed as follows:

⁷17% is for the US and the range between 30% and 40% is more generally admitted for the contribution to growth of Solow residual. It also varies a lot depending on the country and the time period. For example Sakurai et al. ([288]) found, for the group of 10 OECD countries they studied for the period of the 70s and the 80s, that TFP growth was the largest source of growth of GDP in most European countries (more than 60% for Netherlands, Denmark, United Kingdom, France and Italy), about 30% to 40% in Germany and Japan, and 10% to 30% in Australia, Canada and the United States.

$$\Delta t f p_{it} = \sum_f (\alpha_{fit} - \bar{s}_{fi}) \cdot \Delta f_{it} + \theta_{ti}, f = k, l. \quad (2.1.5)$$

It is now a function of the returns to scale on labor and physical capital represented by the expression $\sum (\alpha_{fi} - \bar{s}_{fi}) \cdot \Delta f_{it}$, $f = k, l$, and as previously in equation 2.1.4, of the exogenous time trend, θ_{ti} .

Secondly, knowledge variables were introduced in the production function, which leads in our illustrative setting to rewrite equation 2.1.1 as:

$$Y_{it} = A_i \cdot K_{it}^{\alpha_{ki}} \cdot L_{it}^{\alpha_{li}} \cdot R_{it}^{\alpha_{ri}} \cdot S_{it}^{\alpha_{si}} \cdot e^{\theta_{ti} \cdot t} \quad (2.1.6)$$

where, R_{it} , is the “own” stock of knowledge accumulated by the firm (the sector or the country) at time t , S_{it} , is the “external” knowledge capital available to i in t , and α_{ri} and α_{si} , are their respective output elasticities.

In most studies, the “own” knowledge capital is measured by R&D stock, calculated using the perpetual inventory method, as first proposed by Griliches⁸ (1979 [141]):

$$SRD_{it} = (1 - \delta_{ri}) \cdot SRD_{it-1} + RD_{it} \quad (2.1.7)$$

with δ_{ri} , the depreciation rate of R&D capital and RD_{it} the R&D investment (or flow) at time t .

The “external” knowledge capital is itself usually measured as a weighting sum of the R&D stocks from sources outside the firm, such as:

$$S_{it} = \sum_{j \neq i} w_{ji} \cdot SRD_{jt} \quad (2.1.8)$$

where the weights w_{ji} are “diffusion” parameters measuring the intensity of knowledge transfers (or spillovers), from firm, sector (public or private) or country i , the source of the R&D spillover, toward the firm, sector or country j , the receiver of the R&D spillovers.

If we still assume that there are increasing returns to scale ($\theta_i = \alpha_{ki} + \alpha_{li} > 1$, in equation 2.1.6) TFP, or Solow residual growth, given previously by equation 2.1.5, can be re-expressed as follows:

⁸As writes Wieser (2005, [280]), “(...) [this] R&D capital stock model, introduced by Griliches (1979), asserts that the stock of firm’s technological knowledge is itself a factor of production: R&D activities add to the existing stock of accumulated knowledge of firms, thereby improving the quality of products or reducing the production costs of existing goods and services, i.e., increasing the productivity of firms”.

$$\Delta \ln p_{it} = \sum_f (\alpha_{fit} - \bar{s}_{fi}) \cdot \Delta f_{it} + \alpha_{ri} \cdot \Delta r_{it} + \alpha_{si} \cdot \Delta s_{it} + \theta_{ti}, f = k, l. \quad (2.1.9)$$

Within this new framework, the evolution of TFP is not exogenous anymore and can be explained, from left to right, by scale economies, investment in R&D by firms and the R&D spillovers they provoke, and by an exogenous time trend capturing the influence of omitted factors on the evolution of productivity growth, depending on the scope of the study and the precise methodology and data used. We must underline, that when including knowledge variables in a TFP regression, the parameters associated with the time trend are generally no longer significantly different from zero, reflecting a problem of multi-colinearity between the R&D variables and the time trend⁹, but also the strong effect generally associated with knowledge capital for explaining the evolution of technical change.

Thirdly, some studies enrich the analysis by introducing the product-creating aspects of R&D, *e.g.* Benstein and Nadiri (1991, [29]). These reflect the creation of new product lines or varieties (horizontal innovations) or the quality improvement of existing products (vertical innovations), that will improve the characteristics of the existing goods (increased productivity for intermediate or capital goods, increased utility for consumption goods). This then modifies the demand and the measurement of the output created.

Suppose, for example, that firm's customers demand efficient units of output (in terms of utility, for a consumer, or of productivity, for a producer). Then the demand for firm's i product is a decreasing function of the "quality¹⁰ adjusted price", such as, for example:

$$\Delta y_{it} = \eta_i \cdot (\Delta p_{it} - \Delta q_{it}) + g_t \quad (2.1.10)$$

where $\eta_i < 0$, Δp_{it} and Δq_{it} are respectively the price elasticity of demand, the growth rate of product's price¹¹ and the growth rate of its quality. The last term, g_t , in equation 2.1.10, measures the influence on the demand of the growth of economy or of the industry the firm belongs to.

If the growth rate of quality depends on respectively, with elasticities ξ_{ri} and ξ_{si} , the growth rates of own and external knowledge, we have furthermore:

⁹The reason is that R&D investments, in proportion of output, do not vary much in time.

¹⁰We define "quality" as a global index of product characteristics in terms of productivity or utility, depending if the user of the product is a producer or a consumer.

¹¹In fact, it should be, as Hall *et al.* (2009, *ibid*) explain, "(...) the price of the firm's output relative to the sector or economy (...)" and the same should apply for the product quality.

$$\Delta q_{it} = \xi_{ri} \cdot \Delta r_{it} + \xi_{si} \cdot \Delta s_{it} \quad (2.1.11)$$

Now, assuming that price fully reflects the evolution of TFP , we get, by combining equations 2.1.11 and 2.1.9 in 2.1.10:

$$\begin{aligned} \Delta y_{it} = \eta \cdot \left[-\sum_f (\alpha_{fi} - \bar{s}_{fi}) \cdot \Delta f_{it} - \alpha_{ri} \cdot \Delta r_{it} - \alpha_{si} \cdot \Delta s_{it} - \theta_{ti} \right. \\ \left. - \xi_{si} \cdot \Delta r_{it} - \xi_{si} \cdot \Delta s_{it} \right] + g_t, f = k, l. \end{aligned} \quad (2.1.12)$$

The growth rate of output given by equation 2.1.12 depends on many factors, showing how the richness of the empirical framework has developed in the econometric works. These factors are, from left to right and top to bottom:

1. The price elasticity of demand, the higher this elasticity, the higher the growth of output,
2. The growth of TFP , that is split between the influence of the scale effect, of the (internal and external) knowledge capital and of the time trend,
3. A quality effect, reflecting the product-creating (demand) effects of R&D,
4. The growth rate of demand.

This last expression combines, as in Hall *et al.* (2009, *ibid*) in a similar setting, “(...) *the cost-reducing and product-creating effects of R&D, as well as allowing for imperfect competition, scale economies and markup pricing. (...) The R&D elasticities are now a combination of output elasticities and price elasticities, and cannot be identified separately by this equation alone (...)*”, but identification is possible by using a more structural modeling, as in Bernstein and Nadiri (1991, [29]), where the technology is represented by a variable cost function and the inverse product demand function is explicitly modeled and estimated.

To sum-up, the econometric approach for explaining TFP can be viewed as complementary to growth accounting literature, by re-linking the Solow residual, the “*unexplained*” growth in growth accounting, to R&D spending and various categories of knowledge capital and externalities. Concerning R&D, as detailed data exists from a long time ago and this investment can be made endogenous, it has been the most often investigated way for endogenizing technical change in applied macro models. Besides the TFP effects of R&D, we can also measure its product-creating effects that prove, from the econometric literature (see below, section 2.5.3), to have the strongest growth and employment

impacts at industry or macro level. Or, as we will see in chapter 4, apart from the approach used in NEMESIS, the macro models for EU economy focus mainly on the *TFP* impacts of R&D for endogenizing innovation, which may drastically reduce the economic impacts they measure when assessing for R&D and innovation policies.

2.2 Output elasticities and rates of return of R&D

Econometric studies on R&D using such sophisticated settings like the one in equation 2.1.12 are very few, as are those using the rich framework of cost and profit functions. The most commonly adopted methodology in empirical studies can be represented by the following “extended” production function:

$$Y_{it} = A_i \cdot K_{it}^{\alpha_{ki}} \cdot L_{it}^{\alpha_{li}} \cdot R_{it}^{\alpha_{ri}} \cdot e^{\theta_{ti,t}} \quad (2.2.1)$$

where the time trend is often removed.

In this simplified setting, the production function is “augmented”, in addition to the ordinary production factors, here labor and physical capital, by an R&D variable, in our case the R&D stock accumulated by the firm, the sector or the country. Then two first correlated topics have been investigated: the estimation of output elasticity and of the rate of return of R&D.

2.2.1 Definition of the concepts

Following Terleckyj (1974 [308], 1980, [244]), the “gross” rate of return (before depreciation) of R&D, ρR_{it}^G can be defined, from equation 2.2.1, as the marginal revenue earned from the last euro spent on this asset:

$$\rho R_{it}^G = \frac{\partial Y_{it}}{\partial R_{it}} = \alpha_{ri} \cdot \frac{Y_{it}}{R_{it}}. \quad (2.2.2)$$

This gross rate of return is an increasing function of the size of the R&D’s output elasticity (α_{ri}) and an inverse function of R&D intensity measured by $\frac{R_{it}}{Y_{it}}$. The net rate of return of R&D, ρR_{it} , is then defined as the gross rate of return minus the annual depreciation rate of the R&D capital (δ_{ri}):

$$\rho R_{it} = \rho R_{it}^G - \delta_{ri} \quad (2.2.3)$$

Two estimation strategies, based on this primal approach, are used in the literature.

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The first is a direct estimation of the production function given by equation 2.2.1. We can also use equivalently the *TFP* expression of equation 2.2.1, with for *TFP* calculation a Törnqvist index of the traditional production factors (labor and capital), as in equation 2.1.3:

$$\Delta tfp_{it} = \alpha_{ri} \cdot \Delta r_{it} + \theta t_i. \quad (2.2.4)$$

Estimations are made either on cross-sectional, panel or time series data, at plant, firm, industry or country level. Due to data limitations and the restrictions in the number of elasticity parameters that can be estimated at the same time, the estimation strategy at firm (or plant) level, assumes frequently that the R&D elasticities of output are identical for every firm, such as in our context:

$$\alpha_{ri} = \alpha_r \quad (2.2.5)$$

The second option consists, based on slight modifications of equation¹² 2.2.1, of assuming that it is not the elasticity of output to R&D that is constant in every firms (or industry and country), but the rate of return of R&D. We have this time:

$$\rho R_i^G = \rho R^G \quad (2.2.6)$$

and then:

$$\alpha_{ri} = \rho R^G \cdot \frac{R_i}{Y_i} \quad (2.2.7)$$

Now the R&D elasticities of output differ between firms.

Given the output elasticity, the rate of return is fully determined, and conversely. The main empirical question is then to choose the best option between assuming that output elasticities are constant between firms, or that, alternatively, the rates of return are identical.

To the extent that the output elasticity of R&D should reflect the share of R&D capital rental in production cost, it should differ between firms and its value reflect the differences in R&D intensity. Also, if the R&D capital earns a “normal” return, as physical capital, it should tend to be the same for different firms.

¹²The idea to estimate the rate of return directly was first suggested by Griliches (1973, [140]) and (Terleckyj (1974, [308]) by replacing $\alpha_{ri} \cdot \Delta r_{it}$ by $\rho R^G \cdot \frac{RD_{it}}{Y_{it}}$ in equation 2.2.4, where $\frac{RD_{it}}{Y_{it}}$ the R&D intensity. The advantage of this specification is also that it avoids the calculation of R&D stocks as there are no data on R&D stocks in official statistics.

But, as wrote Hall *et al.* (2009, *ibid*): “*Ex ante*, in the model of inter-temporal maximization [of the firm], over the planning horizon R&D earns the normal rate of return under the expectations which hold at the time of the decision making. *Ex post*, those expectations might not materialize, and hence the marginal investment could earn more or less than the normal rate of return”.

Two major reasons could explain a dissociation between the ex post measured returns and the “normal” rate of return: the highly risky nature of R&D investments and most importantly, R&D externalities.

If R&D capital earns “excess” or “above” normal return, that is to say superior to its rental price, it could therefore be a sign that there are positive knowledge spillovers that push-up the estimated output elasticities and rates of return of R&D capital.

Before exploring the results of empirical studies, additional methodological issues must be considered:

1. The scope of the studies is important. For example, studies working on the cross-section dimension will find generally higher output elasticities of R&D capital, because of the importance of “market stealing” effects in that dimension. Elasticities will be therefore inferior in the temporal dimension, and intermediate when using panel data.
2. The size of elasticities will change depending on the definition used to measure output. Output and *TFP* elasticities found in studies based on Value-Added are on average twice higher than for the estimations based on production, because of the weight of intermediate consumption in production cost (that is about 50%).
3. Finally, when focusing on the R&D capital only, estimations do not control for the existence of positive R&D externalities, like in equation 2.2.1. The output and *TFP* elasticities estimated will be biased upward, and the bias will increase with the level of aggregation of the data. This will be generally the case too, if we do not control for the existence of externalities provoked by the accumulation of other assets, such as investments in ICT and in other intangible assets, like human capital, as the most recent empirical studies, tend to confirm (see chapter 5).

2.2.2 Synthesis of main findings

Following the results of the studies, those based on the first assumption that “output elasticities are constant”, show on the contrary that output elasticities tend to increase with the average R&D

intensity of the firms, industries, or countries that are analyzed. It also confirms the second assumption, that marginal rates of return tend to be the same. For example, in 1984 Griliches and Mairesse already controlled ([147]) the differences in inter-industry rates of investment in R&D, and estimated significantly higher elasticities (0.20) for science-based firms than for those in other sectors (0.10). Verspagen (1995) found similarly, for OECD countries, that R&D activities had a significant effect on firms output in high-tech sectors only, with no significant effects found for both medium- and low-tech firms. Similar results were found by Harhoff (1998, [157]) for German firms, Kwon and Inui (2003, [203]) for Japanese firms, Wang and Tsai (2004, [332]) for Taiwanese firms and by Hernandez *et al.* (2011, [162]) for EU firms. A more recent study by Kancs and Siliverstovs¹³ (2016, [192]) at firm level, using a methodology that allows a non-linear relationship between the R&D intensity of the different firms and their TFP growth rates, confirms and generalizes these previous findings in the literature. Using a methodology based on the generalized propensity score (GPS) approach of Hirano and Imbens (2004, [163]), that allows for explicit modeling of non-linearity in the R&D-productivity relationship, Kancs and Siliverstovs (2016) show notably, for a large set of OECD firms¹⁴ that:

1. *“R&D investment increases firm productivity with an average elasticity of 0.15”* ;
2. *“The impact of R&D investment on firm productivity is different at different levels of R&D intensity - the productivity elasticity ranges from -0.02 for low levels of R&D intensity to 0.33 for high levels of R&D intensity, implying that the relationship between R&D expenditures and productivity growth is highly non-linear, and only after a certain critical mass of knowledge is accumulated, is productivity growth significantly positive”*;
3. *There are important inter-sectorial differences with respect to R&D investment and firm productivity: “firms in high-tech sectors not only invest more in R&D, but also achieve more in terms of productivity gains related to research activities”*.

All these results are in line with those of the empirical literature analyzed by Hall *et al.*¹⁵. (2009, [154]), that find, depending the scope of the study, *“(...) research elasticity ranging from 0.01 to 0.25 but centered on 0.08 or so”* (page 22). The survey of Hall et al (2009, *ibid*) shows in summary:

¹³The previous references to the literature were taken from page 10 of these two authors' 2016 paper.

¹⁴They use as principal data source the EU industrial R&D investment scoreboard that covers 750 EU and non EU firms.

¹⁵Hall et al. provide the more extensive available survey of the literature on R&D and productivity.

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1. That output elasticities for private R&D are high, and if we consider an average R&D intensity in % of value-added in the range¹⁶ of 2% to 4% , they exceed about two to four times their factor share;
2. These “excess” returns for private R&D investments may contribute to TFP growth for at least 0.1 point to 0.2 point per year, and even more if we also take into account the contribution of public R&D;
3. The rates of return of private R&D are higher than those usually found for physical capital, Their magnitude is about 20% to 30% ;
4. Output elasticities of R&D are positively correlated to R&D investment intensities, as illustrated originally by Griliches (1980, [142]);
5. The marginal rate of returns to R&D tends to be the same between firms, sectors and countries, which is a consequence of the fourth point above.

A recent meta-analysis by Donselaar and Koopmans (2016, [104]), focusing on 38 studies¹⁷ performed after 1980 and containing 1214 output elasticities, confirms these general findings, with an average output elasticity of 0.11. Another meta-study by OECD (2015, [253]), that summarizes the results of 200 studies, finds an output elasticity of private R&D of 0.12, comparable as well to Hall *et al.* (2009, *ibid*).

On the size of elasticities between firms and sectors, the study of Ortega-Argilés *et al.* (2015, [259]) confirms the results of Kancs and Silverstovs (2016, *ibid*), that finds that “*According to expectations the estimated R&D elasticities differ across sectors with the highest values recorded for high-tech manufacturing*”. And the same is found also for countries, with higher R&D productivity in the more developed and more R&D intensive countries, as initially illustrated by Coe and Helpman (1995, [63]).

Nevertheless, the survey by Hall, Mohnen and Mairesse (2009, *ibid*), the meta-analysis of Donselaar and Koopmans (2016, *ibid*) and a recent study by Eberhardt *et alii* (2013, [111]), all show that estimated elasticity drops sharply when the analysis takes into account the spillovers between industries and countries. And to take the words of Cameron (1998, [51]), “*One of the more important distinctions between the various studies is the extent to which they have attempted to model knowledge spillovers*”.

¹⁶This average R&D intensity varies depending the scope of the study of course.

¹⁷17 micro, 7 meso and 15 macro level studies (including 1 study containing both macro and meso elasticities).

2.3 R&D spillovers and the social returns of R&D

Besides the output elasticities and the marginal rates of return of R&D capital, econometric literature has also focused extensively on the role played by R&D spillovers, and on the measurement of the social returns of R&D. Following Griliches (1979, [141], 1992, [148]), two types of R&D spillovers are usually distinguished in the applied literature: “knowledge” and “rent” spillovers.

2.3.1 Rent and knowledge spillovers: definition and measurement issues

Knowledge spillovers result from the impossibility to fully appropriate the knowledge that one person’s research will produce. It reflects the public good nature of scientific and technological knowledge, being non rival and only partially excludable. This is the case, as patent protection is incomplete and limited in time, and there are imitation, reverse engineering, circulation of information, that make impossible to keep discoveries and innovations secret, ... And the more the new knowledge is formal and codified, the easier will be its appropriation by competitors and the larger the knowledge spillovers that will take place.

While the “pure” knowledge spillovers above, appear independently of any pecuniary transactions on goods and services, “rent” or “pecuniary” spillovers on the contrary reflect the effect of R&D, or of new knowledge, that is embodied in the goods and services that firms or the consumers buy. It refers conceptually to the effects of product innovation - either horizontal (new varieties) or vertical (improvement of product characteristics) - that increase the utility for a consumer, or the productivity for a producer, of the goods and services that are produced. In both cases, it acts as a “quality” improvement of the products that the user buys.

But as this was first discussed by Griliches (1979, [141]) in his presentation of the concept of “rent” spillovers, as being different from “pure” knowledge spillovers, the former are not true spillovers as they pass through pecuniary transactions of goods and services between producers and customers. To illustrate this, in the case of equipment goods, Griliches (1992, [148], P. 257) writes that *“If capital equipment purchase price indices reflected fully the improvements in their “quality”, i.e. were based on hedonistic calculations, there would no need to deal with it”*. They occur whenever the “quality” improvement of goods and services induced by R&D results in an higher user value of the products than their purchase price. It happens for example because the suppliers may have difficulties in segmenting markets and setting prices that will totally offset the surplus transfer, due to the quality improvement,

for the buyers. Therefore, the more there is competition, the more this type of pecuniary spillover will occur.

Although the distinction between these two types of spillovers is clear-cut conceptually, their respective influence is the most often difficult to establish empirically. It is notably the case as knowledge flows will result for an important part in product innovations and then in user-producer transactions and the capture of pecuniary rents. Rent and knowledge spillovers are therefore for a large part concomitant. Also, as argue Belberdos and Mohnen (2013, [26], p. 15) the distinction is difficult to make empirically as “*Rent spillovers will usually have elements of ‘pure’ spillovers and pure spillovers can also take place in the course of economic transactions*”. For example, for these authors, the literature on knowledge diffusion has largely ignored the “*backward spillovers*” from customers to suppliers, notably for the case of foreign direct investments (inward and outward), and import/export of technology embodied goods. Therefore, “*Sophisticated demand and customers can be a source of spillovers and ideas for innovation*”, more technologically able clients helping “*set and maintain better quality standards for their suppliers (e.g. Javorcik, [175], 2004)*”.

Whatever the concept of spillovers, a common idea is the distinction between the R&D that is performed and the R&D that is acquired, or, in our terminology, between the “internal” and the “external” knowledge. The external knowledge capital is usually measured as a weighting sum of the R&D stocks from the different sources outside the firm, as in equation 2.1.8 “where the w_{ij} weights are proportional to some flows or proximity measures between firms, industry, or country i , the receiver of R&D spillover, and firm, industry, or country j , the source of R&D spillover” (Hall *et al.*, 2009, [155], pp. 27-28). To take the words of Griliches (1992, *ibid*, P.257), “*(...) the ‘weighting’ function, can be interpreted as the effective fraction of knowledge in j borrowed by industry i . Presumably w becomes smaller as the ‘distance’, in some sense, between i and j increases*”.

The way to build these weights has taken various forms in the literature, depending the type of spillovers to measure, and the progress achieved in the methodologies. If for rent or market based spillovers it seems natural to use transaction based metrics between sectors or industries to calculate these weights, the measurement of pure knowledge spillovers, that are not related to any pecuniary transactions, appears more difficult.

Following again the presentation by Griliches (1992, *ibid*), a first distinction in the literature was made between “*horizontal borrowing*”, and “*vertical borrowing*”.

“*Vertical*” borrowing, as in the seminal study by Terleckyj (1974, [308]), follows the first idea that

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R&D is embodied in the goods and services that are purchased, such as intermediate or investment goods. With this approach, the proximity between industries is proportional to their purchases and the more industry i buys from industry j , the more it can benefit from its R&D. For example Terleckyj (1974, *ibid*) cites the spillovers from aircraft manufacturing towards the airline industry, that has benefited from cheaper and higher “quality” planes from technological progress in the aircraft industry. Other classical examples are between electronic components and numerical control machines (Goto and Suzuki, 1989, [135]) or computers (Verspagen, 1997, [327]), or between the computer industry and the financial sector (Bresnahan, 1986, [42]). All are examples of rent spillovers, without the presence of any knowledge spillovers.

“*Horizontal*” borrowing, on the contrary, aims at measuring disembodied spillovers as in the seminal study by Raines (1968, [274]) that uses the classification of industries by product field. The idea is that the closer two firms or industries doing similar things are in the classification, the more they can benefit from each others’ knowledge. Griliches (1992, *ibid*, P. 258) takes the example of the photographic equipment industry and the scientific instrument industry that are close in the classification, they “*may not buy much from each other*” but “*benefit much from each others research*”. But Griliches explains that this approach has major limitations. For example, if we want to generalize it to all industries, how to determine, for example, if “*leather*’ is closer to ‘*food*’ or to ‘*textile*’”? Furthermore, a large part of R&D is performed by large conglomerates and as most R&D data are collected at firm and not at establishment level, the link with product fields is difficult to make.

Alternative methodologies, based on patent data, for measuring either rent or knowledge spillovers, have gained a lot of success, and still continue to be developed.

A first construction that encounters a lot of success was proposed by Scherer (1982, [291]) and is based on “*a cross classification of patents (...) by industry of ‘production’ and industry of ‘use’, to ‘flow-thru’ R&D expenditures from performing to ‘using’ industries*” (Griliches, 1992, *ibid*, P. 259). The idea under these “*technology flows*” matrices is “*to reweigh the available R&D data by line of business into measures of both ‘origin’ and ‘imported’ (used) R&D from elsewhere, assuming that the flow of knowledge to industry i from industry j was proportional to the fraction of j ’s patent deemed to be ‘destined’ for industry i* ” (Griliches, 1992, *ibid*, P. 259).

Another successful and complementary construction uses “*the diversification of a firm patenting activity across technologically determined patent classes to infer ‘overlap’ and closeness measures of inventive activity, as in Jaffe (1988, [172])*” (Griliches, 1992, *ibid*, P. 260). This later approach of

Jaffe (1986, *ibid*, 1988, *ibid*) is more appropriate than the former “*technology flow*” matrices of Scherer (1982, [291], 1984, [290]) for measuring the “*pure*” knowledge spillovers. As Griliches explains (1992, *ibid*, P. 260), contrary to transaction based or technology flow matrices, the distance measure of “*proximity in the technological research space*”, that Jaffe introduces, “*does not imply any flows in particular dimension*”.

2.3.2 The different impacts of rent and knowledge spillovers

The question that fast emerged is to what extent the spillovers measured by the three categories of weighting matrices, differ from or are close the one another? The response to this question is important, as the data needed for building the different matrices may be scarce. Or, if their weights are similar, it should be possible, to measure spillovers, to replace, for example, an input-output matrix by a technology flow matrix, or a technology flow matrix by a technological proximity matrix. Strong similarities between the two first categories of matrices, the input-output and technology flow matrices, that both aim at measuring rent spillovers, should be expected. But we have seen above that rent and knowledge spillovers are themselves for a large part concomitant, and difficult to disentangle empirically. For example, the computer industry that buys an important part of its inputs from the electronic components industry may also borrow a large part of its ideas from the latter, as the pharmaceutical industry does with the chemical industry. And it is possible that the same R&D intensive industries are at the source of the main rent and knowledge spillovers at the same time, and that the two categories of spillovers have similar inter-industry profiles.

van Pottelsbergh de la Potterie (vPP) (1997, [319]) has examined this question in two ways.

He first uses a principal components analysis then a clustering analysis providing “*(...) a comparison of weighting components pertaining to three technology flow matrices, three technological proximity matrices and the input-output matrices of the USA, Canada, Japan, Italy, France, the UK and Germany*” (vPP, *ibid*). All the matrices use the same sectorial classification in 22 industries. The analysis shows that the 7 input-output matrices are very close, reflecting the similarity of inter-industrial transactions in the different countries. The three technology flows matrices were also found, as expected, to be much closer to the input-output matrices than are the technological proximity matrices, showing “*(...) that disembodied knowledge-spillovers are likely to follow different routes than economic transactions*” (vPP, *ibid*). A first conclusion from this analysis is therefore that the distinction made, conceptually, between rent and knowledge spillovers, also appears in the different patterns of

inter-sectorial knowledge spillovers they measure. Technology flow matrices also seem to be in an intermediary position between input-output and technological proximity matrices. Although close to input-output matrices, they are “*more likely*” than the latter to “*catch some knowledge spillovers*”.

Another way to analyze the proximity of the matrices, is to estimate if the spillovers they measure have a similar influence, or not, on productivity growth in the different sectors and countries. For that, we can, for example, introduce R&D spillovers into the TFP equation 2.2.4 above, so we have:

$$\Delta tfp_{it} = \alpha_{ri} \cdot \Delta r_{it} + \alpha_{si} \cdot \Delta s_{it} + \theta t_i. \quad (2.3.1)$$

where , α_{si} , is the TFP or output elasticity of the spillover variable, S , that can be measured either by an input-output matrix, or a technology flows matrix, or by a technological proximity matrix.

By using a similar framework as above, that he applies to his panel of 22 manufacturing industries and G7 countries for the period 1980-1990 , van Pottelsbergh de la Potterie (*ibid*) finds that the (net) rates of return associated to input-related rent-spillover of 117% are much “*smaller than the rates of return to patent-related rent-spillovers computed with Canadian and US technology flow matrices (304% and 820% respectively)*” (vPP, *ibid*). Surprisingly, the impact of knowledge spillovers measured by the different technological proximity matrices varies between 125% and 163%, and is much closer to the values found for input-related rent-spillovers. And “*Since the rates of return associated to the three different technological proximity matrices have a similar amplitude, it may be inferred that these matrices reflect similar links profiles between industries and can be proxied by each other*” (vPP, *ibid*). By contrast, differences in the regression results show that we cannot replace a technology flow matrix by another, nor could the input-output matrix of a country be replaced by the matrix for another country. We can also infer that the higher impact of the technology flow matrices confirms that they catch input-related spillovers as well as knowledge spillovers, and in that sense they are more general than the two other kinds of matrices.

Other interesting results from this study are obtained when estimating the R&D spillover effect across countries. Japan and US are the only countries who seem benefit from significant (net) rates of return to direct R&D. For all the other countries (Canada, Italy, France, the UK and Germany) vPP (1997, *ibid*) even finds no evidence of “*excess*” returns on R&D capital, that earns the same normal rate of return as traditional inputs. Therefore, the impact of including R&D spillover variables in the analysis is generally to reduce the value of output or *TFP* elasticities estimated for their own R&D capital, with private rates of return that turn around zero. It may reflect co-linearity biases between

different R&D variables when working in the temporal dimension, or rather the overestimation of private returns when spillovers, either patent or input-related, are not properly taken into account.

2.3.3 Private and social returns on R&D capital

The preceding effects of “external” R&D on *TFP* did not measure the social return of “each industry’s capital stock”. The (net) social rate of return, $\rho^s R_{it}$, that is closely related to the notion of R&D spillover, is obtained by adding to the private rate of return of own R&D (the benefit to the firm that increases its R&D in the form of additional *TFP* or output, $\frac{\partial Y_{it}}{\partial R_{it}}$), the sum of the returns for all the recipients of that spillovers sender, $\sum_{j \neq i} \frac{\partial Y_{jt}}{\partial S_{jt}} \cdot \frac{\partial S_{jt}}{\partial R_{it}}$; taking into account the depreciation rate of R&D, δ_{ri} , we finally have:

$$\rho^s R_{it} = \frac{\partial Y_{it}}{\partial R_{it}} + \sum_{j \neq i} \frac{\partial Y_{jt}}{\partial S_{jt}} \cdot \frac{\partial S_{jt}}{\partial R_{it}} - \delta_{ri} \quad (2.3.2)$$

The social rate of return that is measured will by definition increase with the number of the potential spillover receivers that are considered in the study. For example, it will be bigger if in addition to inter-sectorial spillovers, we also consider international spillovers in the calculation, where if the recipients are limited to G7 countries, as, for example, in Coe and Helpman (1995, [63]); or ever bigger if we include spillovers from and towards 22 developed countries, as in Coe, Helpman and Hoffmaister (1997, [62]).

In the study of van Pottelsbergh de la Potterie (1997, *ibid*), only inter-sectorial spillovers in each separate country are considered. The main finding is that all G7 countries, except Japan and Canada, benefit from important social returns on R&D, through input-related rent-spillovers. For the author, it could reflect that in these countries there are few measurements of quality adjusted price in national accounts, and that firms are not able to benefit fully from the rents from their product innovations. In the case of patent-related spillovers, apart for Italy, they have high impact and social returns while in the case of knowledge spillovers, only Canada, Germany, Italy and the UK benefit.

These last results of van Pottelsberg de la Potterie therefore show that there are very substantial R&D spillovers and social returns in every country, but their nature and their amplitude may differ “greatly” between countries. It also seems that in the countries where the returns to own R&D are greater, (as in Japan and to a lesser extent US), firms in different industries benefit less from social returns, and conversely.

A complementary study to the one by van Pottelsberg de la Potterie, by Sakurai *et al.* (1996, [288]), brings many additional insights on the impact of embodied R&D. The study is on 10 OECD countries (the G7 countries, as for vPP, plus Australia, Denmark and Netherlands) and uses an input-output approach for measuring the spillovers. Compared to vPP (1997, *ibid*), the study of Sakurai *et al.* deepens the analysis in at least three different ways. It first extends the measurement of spillovers, from those resulting from transaction of intermediate goods in vPP, to include the transaction of capital goods. The latter, if we consider ICT devices or transport equipment, are a more important source of inter-sectorial technology transfers, notably towards service sectors, than intermediate inputs. Secondly, the analysis also covers the service sectors, that nowadays represent about 80% of GDP and employment. It was therefore important to analyze how the technology flows from industry have contributed to the growth of productivity in the different service sectors. Finally, the study also investigates the role played, for productivity growth at the sectorial level, by international technology transfers between the 10 OECD countries under scrutiny.

The study by Sakurai *et al.* confirms, from its input-output accounting based procedure, that “*While innovations are developed mainly in a cluster of high technology manufacturing industries, the main acquirers of technologically sophisticated machinery and equipment are a different cluster of industries in the services sector, with technology generation much more concentrated than technology use*”. It reflects what Verspagen and De Loo (1999, [325]) have called “*the equalization effects of R&D spillovers*”. The usual R&D intensity indicators at sectorial level to spread industries between Low, Medium and High technology industries therefore seems to be an inadequate measure of “*technological sophistication*”, and when considering rather the “*technological sophistication*” of the inputs that are used, the differences between the industries tend to vanish. But as Verspagen and De Loo remarked (*ibid*, P. 218) this “*equalization effect of R&D spillovers*” should not be as strong for all types of spillovers. The reason, as it was analyzed for example by van Meijl (1997, [318]), is that R&D expenditures are concentrated in a few industrial sectors, where “*pure*” knowledge spillovers dominate, while embodied spillovers via production goods dominate in the other sectors. The analysis of international flows of embodied technology demonstrates also that for some countries, a large part of the technology is acquired from imports of high tech equipments, the US leading in this international diffusion of technology. ICT technologies are the bulk of the technology that is acquired in most countries, with strong industry specific patterns: “*IT to high technology manufacturing, communications services and finance, insurance, real estate; transportation technology to transportation services; consumer goods*”

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technologies to wholesale and retail trade; materials technology to agriculture, and to medium and low tech technology manufacturing; fabrication technology to mining, utilities and construction” (Sakurai *et al.*, 1996, *ibid*, P. 8). ICT “*producer*” and “*user*” industries are also those that have encountered the highest rates of productivity growth in every country.

The study, that includes a regression analysis of *TFP* growth, confirms that capital-embodied technology was a major source of *TFP* growth in services, with social rates of return of these flows of embodied technology of about “*130% in the 1970s and 190% in the 1980s*” (Page 3). This strong effect of capital embodied R&D contrasts importantly with the weak effects associated with R&D incorporated into intermediate inputs, that are in line with the previous results of Terleckyj (1974, [308]) and Wolff and Nadiri (1993, [334]). The regression analysis further confirms the strong effect already found by Coe and Helpman (1995) for inter-country spillovers, with also “*(...) the result of the other studies (such as Berstein and Mohnen, 1994, [28]) that this effect is inversely related to size of the country*”. But using, contrary to Coe and Helpman (1995, [63]), disaggregate data, it clarified “*(...) that it comes from increasing international procurement of electronic investment goods done by ICT services sectors*” (Page 27). It is worthwhile underlining that Sakurai *et . (ibid)* do not find any significant effects of outside R&D for manufacturing industries¹⁸. It again confirms the results of van Meijl, [318]) and of other studies (e.g. Griliches and Lichtenberg, 1984, [146], Englander, Evenson and Hanazaki, 1988, [113]) that suggest that the sectors where the own R&D is low, as services, use mainly inputs that embody spillovers, and that in high tech sectors, internal and “*patent*” based R&D represent most of all the R&D that is used. It therefore seems necessary, as suggested for example by (Sterlacchini, 1987, [304], Cincera, 2005, [58], Cerulli and Poti, 2007, [56]) to adopt a mixed approach, including the two types of spillovers, when analyzing the impacts of R&D spillovers.

Looking more closely at the literature, table 2.3.1 displays the results of studies that estimate the rates of return of both “own” and “external” R&D at industry level. We see that both rates of return vary greatly depending of the study. Rates of return of own R&D are in the range of 7% to 56%, in most of the studies 10% to 20%, with an average of 28%. Rates of return of external R&D exceed most often, the rate of return of own R&D by 50% to 100%. On average they reach 45% for the twelve studies we selected, 1.6 times more than the average rate of return for own R&D. The meta-analysis of Donsellar and Koopmans (2016, *ibid*), that compares output elasticities of own and external R&D

¹⁸It is consistent for example with the results of Goto and Suzuki (1989, [135]) , that found for Japanese electronics industry significant effects with technological proximity measures of spillovers but not with intermediate or investment flow matrices.

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Table 2.3.1 – Result of key studies estimating both private and social returns of R&D

<i>Study</i>	<i>Sample</i>	<i>Period</i>	<i>Weighting scheme</i>	<i>Rate of Return of own R&D</i>	<i>Rate of Return of external R&D</i>
Griliches-Lichtenberg (1984)	US, 193 mfg firms	1959-78	Patent flows	11% to 31 % (8%)	50% to 90% (36%)
Sterlacchini (1989)	UK, 15 meg firms	1960-77	Inter-industry transactions, innovation flows	12% to 20%	19% to 20% 15% to 35%
Goto-Suzuki (1989)	Japan, 50 mfg firms	1978-83	Inter-industry transactions	26%	80%
Bernstein (1989)	Canada, 11 mfg firms	1963-83	Simple external sector specific R&D stocks	24% to 47%	29% to 94% (social)
Bernstein-Nadiri (1989)	US, 4 industries	1965-78	Simple external sector specific R&D stocks	7%	9% to 13%
Mohnen-Lepine (1991)	Canada, 12 mfg industries	1975, 77, 79, 81-83	Patent flows	56% (5% to 275%)	30% (2% to 90%)
Wolff-Nadiri (1993)	US, 19 mfg industries	1947, 58, 63, 67, 72, 77	Inter-industry transactions, Investments (capital inputs)	11% 11%	14% 0%
Wolff-Nadiri (1993)	US, 50 industries	1947, 58, 63, 67, 72, 77	Inter-industry transactions, Investments (capital inputs)	19% 19%	8% 9%
Bernstein-Yan (1997)	Canada and Japan, 10 industries	1964-82	Simple external sector specific R&D stocks	17% (Canada) 17% (Japan)	62% to 183% (Canada) 9% to 56% (Japan)
Bernstein (1998)	Canada and US, 11 mfg industries	1962-89	Simple external sector specific R&D stocks	16% (US) 13% (Canada)	28% to 167% (US) 19% to 145% (Japan)
Bernstein-Mohnen (1998)	Canada and Japan, 11 industries	1962-86	Simple external sector specific R&D stocks	44% (US) 47% (Japan)	47% (US) 0% (Japan)
Griffith-Redding-van Reenen (2004)	OECD, 12 industries, 12 countries	1974-90	industry-level TFP gap from frontier	47% to 67%	57% to 105%
All 12 studies	-	-	-	28%	45%

Source: adapted from Wieser, 2005([280])

for 38 studies at “*micro*”, “*meso*” and “*macro*” levels, with 1214 elasticity estimates, provides similar insights, with an average output elasticity of 0.11 for own R&D, and of 0.2 for external R&D. Finally Wieser (2005, *ibid*) analyses the results of more than 50 studies at firm level and also finds, with a meta-analysis, an average private rate of return of 28%, and an average output elasticity of R&D of 0.13. The estimated rates of return (and output elasticities) he estimates for spillover variables are also, in average, 50% to 100% superior to the private ones, “(. . .) *yielding mean social rates of returns (i.e. private plus spillovers) to R&D to the order of 90-100%*” (Wieser, 2005, *ibid*, Page 614).

2.4 The role of public R&D and the importance of “absorptive capacity”

The two preceding sections have highlighted the important contribution of private R&D investments and spillovers to TFP and output growth in developed countries, with nevertheless very contrasted impacts in different sectors and countries. This section complements the analysis by focusing on the distinct impacts that the research performed by the public sector has.

2.4.1 How big is public research compared to private research?

The question of the productivity of public research is important as the research that is carried out by public organizations, either by “Government” or by “Higher Education” sectors, represents a large part of the total R&D in industrialized countries. From the data published on the EUROSTAT portal, it amounted to 30% of total R&D expenditure in EU-28 in 2016. In terms of GDP points, this is 0.23 for government R&D, 0.47 for Higher Education sector and 1.32 for private corporations. The share of R&D performed by the “private non-profit” sector was itself limited to 0.02 GDP point. Looking at the situation for the other important R&D actors in the rest of the world, from EUROSTAT data for the year 2015, the R&D intensity in percentage of GDP was 2.8 in the US, 3.3 in Japan, 4.3 in South Korea and 2.1 in China, with the relative importance of *R&D* expenditure in Government and Higher Education sectors roughly identical to that of EU-28.

Looking now at the origin of the funds, in EU-28 about 31% of the total R&D expenditure was funded by Government, 55% by business enterprises and 11% by foreign sources. Funding by higher education and non-profit sectors was rather limited, about 0.9% and 1.7%, respectively. The situation in the EU contrasts this time with the one prevailing in Asian countries and in the US where the share of R&D that is financed by the private sector represents respectively about three quarters and two

thirds of the total, with a reduced contribution by public funding compared to Europe.

2.4.2 The complementarity between public and private research

Relying mainly on the survey of the literature by Hall *et al.* (2009, [155], *ibid*) and by Beck *et al.* (2017, [24]), the first observation is that private and public research are complementary rather than substitutes. Academic, and to a lesser extent Government research, are more oriented towards basic, or “*fundamental*” research than their private counterpart that is more applied and more focused on development, that is to say on the D side of R&D. Also, as Hall *et al.* (2009, *ibid*, Page 20) stress, a “*good deal*” of government R&D is directed towards the service sectors, while corporate R&D concentrates on industry, and towards “*areas where risk is higher*”. This is the case for basic research, as opposed to “*corporate*” or market oriented research, and also for fields “*(...) where government is already active because there is a public good problem (such as in the areas of defense and health)*”. For Hall *et al.* (*ibid*), this lack of a direct link of public research with the market, and its stronger orientation towards service sectors where the impacts pose many measurement problems, explain that “*(...) a lower rate of return (or a less significant one) is reported by many authors to public rather than private R&D, both at the private and the social level (...)*”. But, on the contrary, a higher return is generally associated with basic research, mainly financed and performed by the public sector, as opposed to applied or development R&D by private firms.

2.4.3 The direct impact of public research on productivity is weaker than that of private research

Even if public R&D is less oriented toward marketable innovations, a straightforward way for investigating its economic impacts is, as for the effects of private R&D, to introduce it in the production function to measure its output or *TFP* elasticity. It can be done at the aggregate level, by adding an additional production factor into the production function of the country, public R&D stock, built traditionally from the perpetual inventory method given by equation (2.1.7), and by using, as for private R&D, an annual depreciation rate of 15%. The analysis can also be conducted at the firm or sectorial level, by adding in the *TFP* equation (2.3.1) a specific spillover variable, S_{it}^P , measuring the stock of external knowledge from public origin available to sector i . We have:

$$\Delta tfp_{it} = \alpha_{ri} \cdot \Delta r_{it} + \alpha_{si} \cdot \Delta s_{it} + \alpha_{pi} \cdot \Delta s_{it}^P + \theta t_i. \quad (2.4.1)$$

where α_{ri} is, as previously, the output elasticity of the R&D stock of the sector, α_{si} , the output elasticity spillovers variable S_{it} , that catches this time only the spillovers from private origins, while the additional output elasticity, α_{pi} , measures the effect of the spillovers from public origins, s_{it}^P .

Similarly as for s_{it} , variable s_{it}^P can be built as:

$$S_{it}^P = \sum_j w_{ji} \cdot SRD_{jt} \quad (2.4.2)$$

where the weights, w_{ji} , measure the intensity of the knowledge transfers from the public R&D source (a research unit, a public laboratory, a university, . . .), j , toward the firm or sector i .

In the most recent studies, these weights are generally calculated by using patent citation techniques, that developed from the end of the 1980s, and represent today a more elaborate way for measuring R&D spillovers and technology flows between, firms, sectors and countries (see Trajtenberg et al., 1997, [314]). As Trajtenberg explains (2001, [313], page 364), this methodological approach takes information from the details contained in patents and on patent citations to build a “(. . .) *quantitative indicators on notions such as the ‘importance’, ‘generality’, and ‘originality’ of patents*”. That way the “spillovers” attached to each patent are traced, and the construction of spillover matrices covering the intra-sectorial, inter-sectorial and international dimensions are made at the same time. By also using the cross classification of patents by supplying and using sectors proposed by Scherer (1982, [291]) or, to take the words of Johnson and Evenson (1997, [177]), between Industry Of Manufacture (IOM) and Sector Of Use (SOU), we can also compute weights for technology proximity matrices (between IOM sectors) and technology flow matrices (from IOM to SOU) at the same time. The knowledge transfers from public research toward private sectors can be retraced as well, by considering the citations of industrial patents to “*university*” patents, like in Jaffe and Trajtenberg (2002, [174]), or to “*non-patent*” references such as scientific publications, like in Narin *et al.* (1997, [243]), that are “*likely*” to be related to academic research.

Besides the extension of the production function to public research capital and externalities, alternative approaches have been used for analyzing the impact of public research, such as the direct analysis of corporate patent citations over time, and the importance of the citations of public sources in them, as in Narin *et al.* (1997, *ibid*), or the estimation of “knowledge production functions” proposed originally by Griliches (1979, [141]), that Jaffe (1989, [173]) uses, for example, for analyzing the link between US state-level corporate patents and both business and university R&D.

The more indirect link of public R&D to the market, compared to business R&D, shows that studies on the productivity impact of public R&D are less numerous than for the private ones, and their results less conclusive. For example, as we have already evoked above, fourteen studies quoted by Hall *et al.* (2009, *ibid*, page 20), report a lower rate of return (private and social) for public than for private R&D, “(...) Poole and Bernard (1992, [271]) even report[ing] instances of negative contributions of government R&D”. Similarly, a recent study by van Elk *et al.* (2015, [317]) found in their preferred estimates, statistically significant output elasticities in a range from -0.02 to 0.07, suggesting (page 2) “(...) that public R&D do not automatically foster economic growth and that the economic return depends on the specific national context”. But their results also tend to confirm that the results of public research, that generally cannot be priced, are difficult to quantify by a macroeconomic approach alone. As Hall *et al.* underline (2009, *ibid*, page 20) “A higher return is also generally reported on basic R&D as opposed to applied or development R&D (Lichtenberg and Siegel, 1991, [218], Lichtenberg, 1993, [217], Link, 1981, [219], Griliches, 1986, [149], Mansfield, 1980, [233]). The longer term impacts, of basic R&D compared to applied R&D, as in Mansfield (1980, *ibid*), could therefore reflect a higher risk that traduces in a higher reward”. For Hall *et al.* (*ibid*), these studies tend therefore to point out the complementarity existing between the types of R&D, and also, as in Link and Rees (1990, [221]), the “(...) higher rates of return to R&D for firms involved in university research, this effect being higher for smaller than for large firms”.

2.4.4 Public research is more basic and crucial for corporate innovation in high tech sectors

Beck *et al.* (2017, *ibid*, Pages 42-43) recall that this complementarity between basic science, corporate R&D and innovation, was illustrated for a long time, with case-study evidence, as in Nelson (1959, [246]), and many authors, such as Rosenberg (1990, [286]), Pavitt (1991, [264]), Nelson (2006, [249]) and more recently Mazzucato and Penna (2016, [239]), have criticized the current tendency of moving public research closer to market with the risk of cutting-off the long term positive impacts of public R&D on industrial innovation and structural change.

Most of the studies focusing on the impact of public basic research on private innovation tend to confirm strong impacts, concentrated in a few R&D intensive industries at the origin of major technological breakthroughs, such as numerical, bio- and nano-technologies. Again according to Beck *et al.* (*ibid*, page 45), Mansfield (1991, [234], and [235]) for example shows that in the US the academic

research was a key factor for firms belonging to the pharmaceutical, electronics, information processing, chemicals and petroleum sectors. Jaffe (1989, [173]) finds similarly for the US, with technology proximity matrices, that public spillovers are particularly important in Drugs, Electronics and Nuclear energy. Henderson *et al.* (1998, [161]) and Jaffe and Trajtenberg (2002, [174]) also show that university patents receive more citations and are more generally applicable than corporate patents, illustrating the more generic nature of public knowledge. For US bio-technologies industry, Toole (2012, [312]) shows that there exists a significant correlation between scientific publications and the number of new molecules. For Europe, Bacchiocchi *et al.* (2010, [18]) using EPO data for France, Italy, Germany, the UK and the US, confirm that university patents are more cited than corporate patents, this result being driven by Chemicals, Drugs, Mechanics industries, as well as US universities. Similarly, for Flemish firms, Cassiman *et al.* (2008, [54]) find, following the methodology used by Narin *et al.* (1997, [243]) for US, that patents that cite non-patent sources, presumably from academic research, are more widely applicable. Finally, Veugelers and Cassiman (2005, [330]) find also an evidence of complementarity between public and private research.

While the impact of public research on economic activity is difficult to see at the aggregate or macro level, studies based on firms' patent data therefore tend to demonstrate the strong positive impact of basic public research on corporate innovation. It is also the case of studies such as Jaffe (1989, *ibid*), focusing on the estimation of knowledge production functions, or on the estimation of the link between public and private research, as in Falk (2006, [117]). In this latter study Falk finds, from a survey and original estimates with a panel of OECD countries for the 1975-2002 period, that public research influences private research with a unitary elasticity. If this last result appears rather optimistic, for Beck *et al.* (*ibid*, page 46) it echoes that of Narin *et al.* (1997, [243]), that the growth of corporate patenting in the 1987-1994 period, was accompanied by an even greater public institution patenting and publishing, with the idea, expressed before by Nelson (1986, [247]) and Klevorick *et al.* (1995, [195]), that basic research by universities “(...) expands the technology space of industry, while Mowery (1995, [242]) concludes that university research expands the efficiency of corporate research”.

2.4.5 Knowledge transfers from public to private need an absorptive capacity

This complementarity between private and public research, and the positive impact of the latter on the efficiency of corporate research, need an absorptive capacity to occur and develop. Richard Levin, at

the origin, with Alvin Klevorick, Richard Nelson and Sidney Winter, of the Yale survey¹⁹ on innovation, was among the first with his co-authors, in a 1987's ([215]) paper on the results of the first survey, to stress the importance of having an absorptive capacity and of investing in research, to be able to understand and use the results of the research conducted by universities. Once again Beck *et al.* (*ibid*, Page 46), Nelson (1986, [247]), Nightingale (1998, [251]) and Pavitt (1998, [265]) provided similar results, that were extended by Cohen and Levinthal (1989, [64], 1990, [65]) and Zahra and George (2002, [337]), for the absorption of research made by firms as well. But there exists other means by which public knowledge is transmitted to firms. For example, Cohen *et al.* (2002, [66]) by also using the Yale survey, quote by order of importance, academic papers conferences, informal information exchanges and consulting. They also find that university knowledge is more important for start-ups and small firms than for established ones. But, as Beck *et al.* underline (*ibid*, page 48), “*Finally, the perhaps second most direct form after the production of scientists of public-private knowledge transfer are public-private research collaborations*”. They quote the findings of Cockburn and Henderson (1998, [61]) on the crucial role of these research collaborations for pharmaceutical industries, with similar findings by Gittelman and Kogut (2003, [132]) in the case of bio-technology firms.

Beck *et al.* (*ibid*, page 48 to 51) stress finally that the “*training of graduates*” (Kaiser *et al.*, 2016) and of “*scientists and engineers*” (Kleivorick *et al.*, 1995, [195]) by universities, are other crucial forms of academic knowledge dissemination to firms. Many additional references can be found in Beck *et al.* (*ibid*) on the positive and significant influence of public research on industrial research, either directly, “*through knowledge transfer*”, or indirectly, “*through the education of scientists*”.

2.5 Six other important topics

The preceding sections have offered a glimpse of the richness of the applied literature on R&D and productivity. They provided a summary of key results concerning private and social rates of return on R&D investments, the distinct impacts of rent and knowledge spillovers, and finally on the impact

¹⁹The Yale survey on innovation was the first survey of this type, aiming at collecting information from corporate R&D directors on the determinants and outcomes of their R&D activities, on the means and efforts for protecting their innovations, how they gather innovation inputs, collaborate with upstream and downstream firms and with universities, and how fast their technologies diffuse. Similar surveys were, and are still conducted in Japan and Canada. In Europe, the “Community Innovation Survey” (CIS) was introduced in 1992 and is harmonised across participants following the OECD ‘s Oslo manual on innovation (1992). The CIS, that was focused at the beginning on manufacturing firms, was extended to services from 2001.

of public research on firms' innovative activity. In this last section we will study certain aspects of the literature we have avoided until now, but that have important impacts on the measurement of the private and social returns of R&D provided by the various studies. These concern successively (1) measurement problems for inputs, outputs and TFP, (2) rates of return of product versus process innovations, (3) distinct output and employment impacts of product and process innovations, (4) the depreciation rate of R&D and the measurement of knowledge capital, (5) time lags between R&D investments and their effects over time, and (6) negative externalities: stepping on toes and creative destruction. Some aspects of these different issues were already treated by Hall *et al.* (2009, *ibid*) that we add to in various ways using the most recent results found in the literature.

2.5.1 Measurement of inputs, outputs and TFP

The estimation of R&D elasticities and rates of returns are influenced by a range of technical and conceptual issues beginning with the measurement of inputs, outputs and TFP. As Hall *et al.* (*ibid*, page 13) underlined, productivity is the ratio between the measure of output and the measure of inputs. If outputs or inputs are badly measured, it will bias the measurement of productivity, and as well the contribution attributed to R&D for explaining the *TFP* growth in the empirical studies. There are also alternative measures for output such as production, value-added or sales, than can lead to different measurements for R&D elasticities (e.g. Griliches and Mairesse, 1984, [147], or Mairesse and Hall, 1994, [229]). On the input side, an important source of bias comes from the fact that R&D expenditures are composed of labor, capital and material costs that pose a “*double-counting*” problem, unless, as Hall *et al.* wrote (*ibid*, page 13), “(…) *the conventional inputs are cleared of their R&D components*”. Cunéo and Mairesse (1984, [83]) found, for example, an important downward bias when the inputs are not corrected for R&D double-counting. If the output is measured by value-added, net R&D should also be added on output side²⁰, and it was only rarely the case. The bias on R&D elasticities can therefore go in both directions.

Finally, as Hall *et al.* explained (*ibid*, Page 13), even if other important sources of biases exist, such as the assumptions about the production technology, returns to scale and the utilization rate of production inputs, “*A more substantial problem, particularly acute in relation to R&D, is the incorporation*

²⁰This problem has been recently solved, as R&D, that was previously accounted as an intermediate consumption, is now considered as an investment in national accounts. It is the case in the United States from 2012, and from 2014 in the European Union. The measurement of GDP and sectorial value-added was therefore also revised upward, for the amount of net R&D returns.

of quality changes in price deflators”. We have already underlined, in the preceding sections, that the estimated private and the social returns of R&D are influenced by “quality” measurement problems underlying the concept of rent spillover. The overestimation of prices in R&D-intensive industries leads as to underestimate their output and rate of return, and, conversely to overestimate the rate of return in industries that use their output as input²¹. Productivity gains and returns are accordingly often imputed to the wrong industries. To get a closer idea of the amplitude of the problem, the American Senate Boskin Commission²² has analyzed that precise question, concluding that, in 1996, “(...) the Consumer Price Index was likely biased by 1.1 percentage point per year, with about half of the bias attributable to problems with accounting for quality change and new goods” (Boskins *et al.*, 1997, [36], table 3, cited by Groshen *et al.*, 2017, [150], Page 197). This 1.1 over statement of consumer price increase means, conversely, that GDP growth was also underestimated 1.1% per year, of which 0.6% directly attributable to the problems posed by quality changes and the arrival of new goods!

In a more recent study, Lebow and Rudd (2003, [211]) estimated that in 2001, the bias in CPI caused by quality change and new products was limited to 0.37%, reflecting, for Groshen *et al.* (*ibid*, Page 197), the methodological improvements introduced by the Bureau of Labor Statistics after the Boskin Commission. Groshen *et al.* that belong to the Bureau of Economic Analysis in charge with the BLS of the measurement of GDP and price indexes, underline that the problem is not new and for example the 1920s “(...) saw a rapid introduction of new goods such as indoor plumbing, electricity, and radios, as well as dramatic improvement of existing products such as automobiles and airplanes (...) over the past century, technical innovation has continued to improve existing goods and has led to the introduction of a myriad of new products”. Despite the methodological improvements for measuring the price of products, the problem remains an important one, as price adjustments for quality improvements are generally easier to make for goods than for services, whereas the services represent an increasing part of both production and consumption. Finally, in a recent paper, Aghion *et al.* (2017, [3], Page 2017) advocate in that direction that the “(...) missing growth has not declined over the past thirty years, and in fact seems to have risen modestly. A corollary [given the reduction

²¹To illustrate the order of magnitude of the “errors” that could be reached on the measurement of the rate of returns, Hall *et al.* (*ibid*, page 12), take the example of Griliches (1994, [144]) that, when measuring the rate of return across R&D intensive industries in the US, “(...) obtains an estimated rate of return to R&D of 35.7% for the 1973-89 period. When the computer industry, which is the only one that has quality changes incorporated in its output price index, is excluded from the regression, the rate of return drops to 13.4%. But when TFP growth in semiconductors and pharmaceuticals is also corrected for quality change in outputs, and TFP growth in the computer industry is corrected for quality change in the inputs of semiconductors, the estimates rise again to 34.8%, even without including the computer industry”.

²²The members of the advisory commission were Michael J. Boskin (chair), Ellen R. Dulberger, Robert J. Gordon, Zvi Griliches, and Dale Jorgenson.

of TFP growth] is that missing growth appears to be a growing fraction of true productivity growth”.

2.5.2 Rate of return of product/process innovations

“By and large, R&D expenditures are spent on designing new products, which will provide more consumer or producer value per unit of resources used, or new processes, which would reduce the resources requirement of existing products” (Griliches and Lichtenberg, 1984, Page 472). In most studies disaggregating R&D data in this way, the return estimated for process R&D is higher than for product R&D. It is the case, for example, in the following studies quoted by Hall *et al.* (ibid, Page 20): Clark and Griliches (1984, [60]), Griliches and Lichtenberg (1984, [145]), Link (1982, [220]), Terleckyj (1982), Scherer (1982, [291], and 1983, [292]) and Hannel (1994, [156]). As Hall *et al.* report, there are numerous reasons for that, like the simple fact that the two types of R&D are often complementary and their impact difficult to disentangle, and that product innovation often involves a “start-up and debugging phase” lowering its returns in the short run. Even more importantly, the effects of product R&D are difficult to measure because of the poor reflection of quality improvement in the price indices, notably, as we have underlined, for services and for the goods and services produced by the public sector.

2.5.3 Output and employment impacts of product and process innovations

On the other hand, any output or employment impacts estimated for product innovations are generally superior than those that are measured for process innovations. Following Hall (2011), these distinct characteristics of process and product innovations can be illustrated analytically with this set of two equations (1) for demand addressed to a firm:

$$q = \eta \cdot p + \varphi \cdot k$$

with q the growth rate of demand, η the price elasticity of demand, p the growth rate of price, φ the elasticity of demand to firms’ innovation and k the growth rate of innovations, and (2) for the productivity equation of the firm:

$$q = a + \alpha \cdot c + \beta \cdot l + \gamma \cdot k$$

with q the growth rate of value-added, α the cost share of physical capital, c the growth of physical capital, β the cost share of labor, l the growth of the labor input, and finally γ the productivity effect

of innovations. Then by combining these two equations, one can show that the impact of product innovations on firms' revenue growth rate ($r = p + q$), that expresses: $\frac{-\varphi}{\eta}, \eta < 0$, is always positive, while the impact of process innovations ($\gamma \cdot \frac{\eta+1}{\eta}$) is always small, or negative (if $\eta > -1$), the same being true equally for the employment impacts of innovations. Hall (2011) confirms this result by applying the CDM model (1998 [81]) to a set of 15 EU manufacturing firms using the CIS 3 survey, with both weak or negative estimated impacts of process innovations on real revenue and employment, and conversely, strong positive impacts of product innovations.

Similarly, surveying the literature in great detail for the impacts on employment of process and product innovations, Peters *et al.* (2014, [268]) show that the impacts on employment of process and organizational innovations are smaller than the effects of product innovation, in all phases of the business cycle. The authors also find high productivity impacts and reduced employment in manufacturing after process and organizational innovations, and in services for organizational innovations .

Investigating more closely the distinct impacts that innovations have on employment in service industries, Damijan and Star (2014, [87]) find that like in industry, studies generally find a positive impact after product innovations, and a negative impact after process innovations, and no major differences between industry and services seem to emerge from the literature (see also also Harrison *et al.*, 2008, [158]; Bogliacino and Pianta, 2010, [33]).

It is therefore particularly important to represent these two different types of innovations in the macro simulation model designed for the assessment of research and innovation policy, in order to attribute the correct impacts on GDP and employment.

2.5.4 R&D depreciation rate and knowledge capital measurement

As we have seen, nearly all the literature on R&D and productivity, and on the estimation of the rates of return on R&D capital, was based on the construction of knowledge stocks obtained from the accumulation of R&D investments by the perpetual inventory method, as proposed initially by Griliches (1979, [141]) : $SRD_{it} = (1 - \delta_{ri}) \cdot SRD_{it-1} + RD_{it}$

where, as in equation 2.1.7, SRD_{it} is the stock of R&D available capital to i at date t , δ_{ri} the depreciation rate, generally 15%, and RD_{it} the R&D investment at time t .

According to Hall *et al.* (*ibid*, Pages 16 to 19), two principal problems emerge from this formalization.

Firstly, R&D stocks cannot be observed, so a first initial “*benchmark stock*” is required, and generally

built by assuming a constant depreciation rate and constant growth rate of R&D from past observations. As R&D data are obtained from results of surveys and are provided in current values, it is also necessary to use a deflator. While “*The ideal for constructing a deflator for R&D expenditures would be a Divisia index of the prices of the various components of R&D (...)*” (Hall *et al.*, *ibid*), in practice the choice of the R&D deflator does not seem to matter greatly, and in most studies, the GDP deflator, that averages the labor and capital costs, is generally retained.

Secondly, the formalization that is used supposes a constant depreciation rate of knowledge capital. Therefore the problem of choosing this rate remains. Hall *et al.* (*ibid*) emphasize that “*Determining this rate is difficult if not possible, for at least two reasons. First, the appropriate depreciation rate is endogenous to the firm’s own behavior and that of its competitors, in addition to depending to some extent on the progress of public research and science. (...). Second, identifying the depreciation rate independently from the returns to R&D requires the determination of the lag structure of R&D in generating returns*”. In spite of these difficulties, Hall *et al.* (*ibid*, page 17) report that researchers have attempted to estimate the depreciation rate of private R&D directly in various ways: from patent renewable data, as in Bosworth (1978, [38]), a direct estimation of the depreciation rate, as in Klette (1994, [193]), Tobin’s q market value equation estimations, as in Hall (2005, [17]), or in experimenting with different rates in constructing the knowledge stock, as in Griliches and Mairesse (1984, [147]). This last approach shows that output elasticities estimated for R&D are nearly unchanged when the depreciation rate varies from 8% to 25%, the range validated by the literature, and “*Because of this evidence, most researchers use the 15 per cent that Griliches has settled on his early work*”.

But if the value of output elasticity is not influenced by the choice of the depreciation rate, it is not the case at all for the values of the “gross” and “net” rates of return on R&D that are derived from this elasticity, through, respectively, equations 2.2.2 and 2.2.3 above. The value of the depreciation rate will therefore modify the measure of the true knowledge stock that influences the gross rate of return in equation 2.2.2, and the conversion of gross returns to net returns from equation 2.2.2 to equation 2.2.3.

Similarly, the gross and net rates of returns that are computed by applied macro simulation models will be importantly influenced by the choice retained for the depreciation rate of knowledge capital.

2.5.5 The time lags between R&D investments and their effects over time

As for the depreciation rate that conditions the duration of the effects of knowledge capital over time, there is no reason to suppose that R&D investments have an immediate impact. On the contrary the literature underlines important time lags between R&D investments and the first effects on innovation, and from innovation to productivity and market impacts. Hall *et al.* (*ibid*, page 18) report for example a three year mean lag between R&D and innovation (Mansfield *et al.*, 1971, [236]) and similarly, from survey data, Ravenscraft and Scherer (1982, [276]) relate a typical lag time between the beginning of “*development*” and the first introduction of new products of one to two years for 45% of firms, of two to five years for 40% of firms, and superior to five years for the remaining firms. They conclude that the lag structure is “*bell-shaped*” with a mean lag of 4 to 6 years. Ducharme and Mohnen (1996, [109]) found similarly lags of 5 to 6 years for own R&D, and up to 11 years for spillovers. And even if there is evidence that the “lag effect drops sharply after two years” (Hall *et al.*, *ibid*, page 19, quoting the results of Griliches and Mairesse, 1984, [147]), as Verspagen and de Loo (1999, [325], page 233) underline “*time dimension*” is also particularly important for the analysis of R&D spillovers that occur with an “(...) average time lag of around four-and-one-half years between the spillover and the time of R&D”. The authors show notably, from their analysis based on the use of technology flow matrices, that the effects of spillovers tend to spread between sectors over time, illustrating the “*equalization effect*” of R&D spillovers, that “(...) leads to a more equal distribution of knowledge over sectors”.

It is also important to underline that the “intrinsic” effects of R&D investments and knowledge capital, that is to say their productivity, can also vary. For Caballero and Jaffe (1993, [50]) three main aspects of the process of diffusion of information can explain this phenomenon: “*First, there is the concept of endogenous obsolescence (...). Unlike the traditional notion of ‘depreciation’, the obsolescence of old ideas ought to be connected to the distance between ideas in the state rather than the time dimensions. That is, it is not the passage of time that makes old ideas less useful, it’s the accumulation of new ideas. Second, inventors take time in seeing others’ inventions, which suggest that there are diffusion lags (...). Third, the spillover intensity between cohorts of ideas may vary independent of the effect of obsolescence of old ideas*” (Caballero and Jaffe, *ibid*, pages 25 and 26).

Applying a “*citations function*” methodology to US patent data, the authors show therefore that “(...) the rate of obsolescence of knowledge rose from about 2 or 3% per year early in the century to about 10-12% per year at the end of the 1980s” (Caballero and Jaffe, *ibid*, page 68). While the authors find that the “*process of diffusion of knowledge is quite rapid (...)* 70% of product innovation

[being] (were) known and understood by rival firms within 12 months (...) the spillover potency fell by a factor of 5 over the century, and 25% for the post-war period” (Caballero and Jaffe, *ibid*, pages 68 and 69). For the authors, “*Is has implied a fall in the private productivity of research of about 30% between the late of the 1950s and 1990*” (*ibid*, page 69). This deep productivity slowdown would come from “(...) a fall in research productivity connected to a decrease in the potency of old knowledge in generating new ideas” (*ibid*, page 70). This decline, as the authors explain page 72, would finally come from the fact that with the multiplication of product varieties, the research would “*steadily becoming ‘narrower’ and, hence, generates fewer spillovers because each new idea is relevant to a smaller and smaller set of technological concerns*”.

2.5.6 Negative externalities: stepping on toes and creative destruction

It is finally important to notice that the econometric literature we have surveyed focuses nearly exclusively on the role played by two positive externalities arising from R&D and innovation activities, and that they explain an important part of the discrepancies existing between their private and social rate of return. They are the “pure knowledge” spillovers, also called in the literature on endogenous growth, the “*standing on shoulders*” effect, and the “*rent*” spillovers, that as we have seen come from a “*surplus appropriability*” problem. But R&D and innovation activities also provoke negative externalities. There is first, as we have just underlined in the case of the Caballero and Jaffe study (1993, [50]), that new knowledge makes old knowledge obsolete and that new inventions can become more difficult with the accumulation of past inventions. If this last effect, that Jones (1995b, [180]) had called the “*fishing out*”, must play, it is generally admitted that the “*standing on shoulders*” effect is the stronger, and that inter-temporal knowledge spillovers have a net positive effect on research productivity, even if it can decline or reduce in time. Second, there is the “*congestion*” externality, that Jones called “*stepping on toes*”, that arises when rival firms that race for innovation, duplicate research done by the others, and in this way reduce research productivity that is measured at a more aggregated level. Then is third the famous “*creative destruction*” concept that was introduced by Schumpeter (1942, [294]), when innovations by firms make old products and processes obsolescent. This third negative externality relates to the entry/exist of firms and to “*market stealing effects*” and reflects, like the “*stepping on toes*” effect, the market rivalry of R&D and innovation.

Picking some examples of this market rivalry of R&D from the literature, Beck *et al.* (2017, *ibid*) report notably that in Bloom *et al.* (2013, [32]), that take into account at the same time the positive

knowledge spillovers they measure from patenting, and the negative market stealing effects from sales of rival firms in the US on the period 1981-2001, that “(...) [*positive*] *knowledge spillovers dominate market rivalry, so the social return is at least twice as high the private rate of return*” (Beck *et al.*, *ibid*, page 21). They confirm the previous results by Czarnitzki and Kraft (2012, [84]) using a similar methodology. In a recent paper, Garcia-Marcia *et al.* (2019, [131]) find also for the US (page 4), that most growth comes from “*incumbent*” firms and not from “*entrants*”, and that most growth occurs through quality improvement, own-variety improvement by incumbents being larger than creative destruction by entrants. They find finally that “*The contribution of creative destruction is around 25 percent of growth, with the remainder mostly due to own innovation by incumbent firms*”(ibid, page 4), but with a decreasing contribution of entrant firms and creative destruction between 1976-1986 and 2003-2013.

We see from the results of these studies on negative externalities, that were inspired by recent endogenous growth theories, presented in the next chapter, that taking them into account does not challenge previous results of econometric studies on R&D, where they were mostly absent. The reason for this was already examined in detail by Jones and Williams (1998, [182]), within an analytical framework involving the two positive externalities at the same time (“*Standing on shoulders*” and “*surplus appropriability*”) and two negative ones (“*Creative destruction*” and “*stepping on toes*”), that clearly links the new growth theories to the empirical results in R&D and productivity literature. As Jones and Williams write, “*The results are rather surprising (...) we show that these estimates in the literature represent lower bounds on the social rates of return to R&D*” (ibid, page 2) and to continue page 13: “*The general conclusion from this literature that the social rate of return to R&D is very large evidently survives rigorous analysis in the context of the new growth theory. How does the productivity literature nearly get the right answer? The explanation involves two different errors that nearly offset (...). The return to society due to knowledge spillovers (...) exactly offsets the capital loss due to the fall in the value of ideas as ideas become less costly to generate over time due to the accumulation of knowledge. What remains is the capital gain due to the increase in the value of designs resulting from the growth of R&D (...)*”.

Chapter 3

The New Growth Theories

Chapter 3. The New Growth Theories

The empirical literature on R&D and productivity has underlined the major role played by knowledge spillovers for productivity growth in industrialized countries. They create increasing returns and then large discrepancies between the private and the social returns from R&D investments; the social returns exceeding, on average, at least double the private ones.

This evidence of increasing returns provoked by knowledge spillovers has major implications for the representation of the growth process, and for economic policy. If the knowledge created by research investments cannot be fully appropriated by firms, there are market failures and private investors will spontaneously under-invest in R&D. The direct consequence is that the decentralized equilibrium of the economy is sub-optimal, and collective decision making and state policy intervention are necessary for maximizing the social welfare.

On the theoretical side, the growing evidence of the central role played by knowledge spillovers in the growth process has led, over a few years, from the late 1980s to the end of the 1990s, to profound modifications in the neoclassical model of economic growth inherited from the seminal models of Solow (1956, [300]) and Swan (1956, [306]), known as the “New Growth Theories” (NGT hereafter).

The main difference between the approach of the new growth theorists, compared to the one of the proponents of the previous neoclassical economic consensus with the RCK model¹, comes from the respective role they attribute to investment and to spillovers as sources of growth. This divergence was, for example, at the core of the debate that opposed, in June 1996, Dale Jorgenson, an ardent defender of the RCK model, and Gene Grossman, an eminent representative of the NGT, on the occasion of a conference organized by the Federal Reserve Bank of Boston, on the theme of “*Technology and Growth*”.

For Dale Jorgenson (1996,) [85], the RCK model is very efficient at analyzing steady states with constant rates of growth, that was demonstrated by the empirical support of Kuznets (1971, [202]). The contribution of the Solow residual in the model, that regroups all the exogenous factors, such as technological spillovers, that influence productivity, has nearly vanished, passing from 87.5% when Solow wrote his article in 1956, to less to 17% in 1996, because of the development of constant quality indexes for both capital and labor inputs. For Jorgenson, this development has narrowed the difference between the NGT and the RCK models. Physical and human capital accumulation, “*properly measured*”, are still the main drivers of economic growth, and “*Fortunately, a new empirical consensus*”

¹We refer to the Ramsey (1928, [275]), Cass (1965, [53]) and Koopmans (1965, [196]) model, that introduces, from the original formulation of Ramsey (1928), endogenous inter-temporal consumption and savings in the Solow (1956) model, where the savings rate was originally exogenous. The RCK model is therefore the first, fully accomplished version of the neoclassical model of economic growth.

on economic growth would require only a relatively modest reinterpretation of the neoclassical framework established by Solow (1956, [300], 1970, [298], 1988, [299]), Cass (1965, [53]) and Koopmans (1965, [196])". (Jorgenson, 1996, *ibid*, page 70).

But for Gene Grossman, "Jorgenson confuses the issue, "(...) when he equates identifying the 'sources of growth' with 'endogenizing' growth". (Grossman in Fuhrer *et al.*, [129], page 85). And to pursue this: "(...) An accounting procedure that attributes output growth to investment has not endogenized growth, unless the factors that generate incentives for investments are also explained". Contrary to Jorgenson for whom only "a relatively modest reinterpretation of the neoclassical framework" should be necessary, to adapt it to "knowledge-based" economies, for Grossman "The neoclassical growth model, with its built-in assumptions of constant returns to scale and perfect competition, is not well suited for studying innovation. Investments in knowledge are up-front investments that naturally imply increasing returns to scale in production. Firms cover these fixed costs by charging prices in excess of marginal costs. Therefore, there is little choice but to study innovation in a setting that allows for imperfect competition, despite the ambiguities in policy advice that this implies".

The specificity of knowledge compared to other economic goods is the existence of important increasing returns associated with investment in knowledge, leading to imperfect competition and monopoly rents. Competition is no longer between firms producing a homogeneous product with similar characteristics, but between firms producing differentiated goods and compete for monopoly rents. The specificity of knowledge is also that it has the characteristics of a public good. It is costly to develop new knowledge, but once it has been produced it can be re-used indefinitely at zero marginal cost. The accumulation of knowledge is therefore potentially unbounded, leading to a succession of new products and services, new processes and new forms of organizations; with also, new monopolies succeeding the old ones because of competition and creative destruction. There is still competition, but it is not the one prevailing in the Solow's representation of growth.

The challenges and the implications that the existence of knowledge externalities poses for the representation of the growth process are therefore numerous. In the RCK model, the endogenous growth process is stopped by the law of diminishing returns to capital that raises the marginal production cost and prevents capital accumulation. The solution imagined by Solow (1956) and Swan (1956) was to introduce exogenous technical change in the model, a solution that has the advantage, in common with the diminishing returns on traditional factors, of ensuring an unique and stable equilibrium, and a steady growth rate of GDP per capita. But by excluding the process that generates the technical

change itself from the model, it finally has very little to teach us about the economic forces at the source of growth.

To reform this RCK model, the approach followed by the NGT was therefore to endogenize technical change in it. But by doing that, many difficulties emerged, and this process of endogenization has been gradual and is still continuing.

In this chapter, without entering into the technical details of the different models, we will present their more salient features and how each model complements, improves or encompasses, the others. We will also focus on a set of two equations, that like Romer (1986) we will call the $F(\cdot)$ and $G(\cdot)$ functions, that are sufficient for summarizing and comparing the endogenous growth properties of the different models.

Therefore, within this setting of two equations, $F(\cdot)$ is the production function of the final output that has, in the different NGT models, the following generic form:

$$Y_t = F(A_t, X_t), \quad (3.0.1)$$

with X , a compound aggregate of the traditional production inputs used in the production of the final output, and A the stock of knowledge used in production, that is at the source of the increasing returns.

We have most of the time:

$$Y_t = A_t \cdot X_t, \quad (3.0.2)$$

In the NGT model, the production of new ideas has the following generic form:

$$\Delta A_t = G(A_t, R_t), \quad (3.0.3)$$

where R represents the resources that are committed to research, and A the inter-temporal knowledge externality that pushes up the productivity of research in time.

The combination of the equations $F(\cdot)$ and $G(\cdot)$ therefore determines the relationship between the R&D effort, the innovations as well as the growth rate of output per capita in the economy. The latter, contrary to the RCK model, is endogenous, to the extent that the R&D investments, at the origin of the innovations and externalities that create monopoly rents, are themselves endogenous and result from profit maximization by firms, and inter-temporal utility maximization by households.

As we will now see, starting from the initial RCK model of economic growth with exogenous technical change the various NGT models differ in the way they specify the F and G functions, or in the way they construct the A variable. What they have in common is to introduce rigorous micro-economic foundations in the long-run growth neoclassical model first introduced by Solow (1956) and Swan (1956), by generally distinguishing three economic sectors: (1) The research sector, with free entry and pure and perfect competition, that has the role to produce new ideas; (2) an intermediary goods sector in monopolistic competition, that introduces the innovations onto the market, by exploiting the new ideas produced by the R&D sector commercially; (3) the sector producing the final goods, functioning in pure and perfect competition, that uses new intermediate goods in its production process.

3.1 The RCK Model

Before presenting the various generations of models that aimed at endogenizing the technical change in the RCK model, we start here by recalling all the refinement that this Ramsey, Cass, Koopmans model represented at the time it was elaborated, from the first versions with exogenous saving rates by Solow (1956, [300]) and Swan (1956, [306]), up to the elaborated inter-temporal general equilibrium models with an endogenous saving rate by Cass (1965, [53]) and Koopmans (1965, [196])².

3.1.1 The Kaldor Facts

At that time, as related by Jones and Romer (2010, [181]), Nicholas Kaldor (1957, [188], 1961, [189]) stated six “stylized” facts that emerged from the development of national accounts, summarizing what economists had learned from the analysis of twentieth-century growth. These are the following (from Kaldor, 1961, P. 178-179, and as enumerated by Jones and Romer, 2010, P. 225):

1. *“Labor productivity has grown at a sustained rate.*
2. *Capital per worker has also grown at a sustained rate.*
3. *The real interest rate, or return on capital, has been stable.*
4. *The ratio of capital to output has also been stable.*

²We will focus, here, on the version of the model with exogenous saving rate, as the endogenization of the saving rate by Cass (1965) and Koopmans (1965) is not central to our argumentation.

5. *Capital and labor have captured stable shares of national income.*
6. *Among the fast growing countries of the world, there is an appreciable variation in the rate of growth “of the order of 2-5 percent”.*

For Jones and Romer (*ibid*, P. 225), “*These features are embodied in one of the great successes of growth theory in the 1950s and 1960s, the neoclassical model*”. And if the authors of the models “*have moved onto the representation of several others*”, these former are still at the core of the general characteristics that a model must include.

3.1.2 Factor endowment and production technology

For this, let's start with the Solow-Swan model with exogenous population growth and exogenous technical change.

In the simple setting of the Solow-Swan model, there is no government³, the economy is closed and it can be resumed by one representative consumer and one representative firm.

On the production side, the production function, $F(\cdot)$, includes three production factors:

$$Y_t = F(A_t, K_t, L_t) \quad (3.1.1)$$

with Y_t , the final output; A_t , the stock of technological knowledge; K_t the physical capital stock and L_t , the labor.

The supply of labor is supposed to grow at an exogenous exponential rate n , so we have:

$$\frac{\Delta L_t}{L_{t-1}} = n \quad (3.1.2)$$

Similarly to labor, “technology” is supposed to grow at a constant exogenous exponential rate, g :

$$\frac{\Delta A_t}{A_{t-1}} = g \quad (3.1.3)$$

In the model technology has the nature of a public good, being publicly available and not excludable. It acts as a pure knowledge spillover, and its growth rate, g , can be assimilated to the progress of science.

³Introducing government final consumption in the model would not change the analysis.

The capital stock is obtained from the accumulation of forgone output and it depreciates at the constant exponential rate δ , therefore:

$$K_t = (1 - \delta) \cdot K_{t-1} + I_t \quad (3.1.4)$$

with I_t the investment that is realized at the date t .

The aggregate production function is assumed to be of Cobb-Douglas type with “*labor augmenting*”⁴ technical change, according to the first of the Kaldor Facts enumerated above, and it can be written:

$$Y_t = (A_t \cdot L_t)^{1-\alpha} \cdot K_t^\alpha \quad (3.1.5)$$

In equation 3.1.5, the term $A_t \cdot L_t$ therefore represents “*effective labor*”, or the “*efficiency units*” of labor that are used in production.

The choice of the Cobb-Douglas production function is certainly the most important (if not the “*only*”) feature that distinguishes the Solow (1956) model from the previous Harrod-Domar (Harrod, 1939, [159]Domar, 1946, [103]) model of economic growth, where the use of labor and capital is made with fixed proportions, and whenever labor and capital does not grow at the same rate, it leads to instability. On the contrary, with the Cobb-Douglas production function, labor and capital can substitute each other continuously at constant rate to produce a given level of output. Furthermore, considering the growth of output, two sets of properties of this “neoclassical” production function are fundamental for preventing instability and to guarantee that the growth rate of the economy will converge towards a balanced growth path:

1. F is continuously differentiable twice and under constant returns to scale in K and L , it exhibits diminishing marginal products in K and L , such as:

$$\frac{\partial F(\cdot)}{\partial Z} > 0 \quad \text{and} \quad \frac{\partial^2 F(\cdot)}{\partial Z^2} < 0 \quad (3.1.6)$$

with $Z = K, L$. It means that more capital, K , if everything else (labor, L , and technology, A) is kept constant, will lead to more output Y , but output will increase less and less as we add new units of capital (and the same is true for labor). This “law of diminishing returns” to capital

⁴As the Cobb-Douglas production function is additively separable, assuming “*labor augmenting*”, “*capital augmenting*” or “*Hick’s neutral*” technical change does not change the analysis, as the true type of technical change cannot be identified empirically within this framework.

(and labor) is very important, as it explains why capital accumulation and output growth will stop if there is no growth of the labor force. It also explains why output per *capita* (by assuming that all the population is employed) will stop increasing if there is no growth of technological knowledge, as we will see below.

2. There are the “*Inada Conditions*” that impose limits on the marginal products of labor and capital, such as:

$$\lim_{K \rightarrow 0} \frac{\partial F(\cdot)}{\partial Z} = \infty \quad \text{and} \quad \lim_{K \rightarrow \infty} \frac{\partial F(\cdot)}{\partial Z} = 0 \quad (3.1.7)$$

with $Z = K, L$ again. These second conditions are regularity conditions ensuring that the economy will not converge toward a degenerated steady state. They imply that the first units of labor and capital have such a high marginal product, and the last units, when the factor endowment becomes sufficiently abundant, such a low one, that the economy will always converge towards an interior stable equilibrium.

3.1.3 The Firms’ optimum and the solving of the model

Concerning the solving of the model, on the producer side, given its production function $F(\cdot)$, the stock of technological knowledge A_t , and the factor prices R_t and ω_t , a firm will choose the levels of capital, K_t , and of labor, L_t , that maximize its profit:

$$\max_{K_t, L_t} P_t \cdot F(A_t, K_t, L_t) - R_t \cdot K_t - \omega_t \cdot L_t \quad (3.1.8)$$

with P_t the price of final output.

The markets for final output and production factors are all supposed competitive, and the solving of this problem leads to the well-known first order optimality conditions equating the marginal products of factors to their prices:

$$P_t \cdot \frac{\partial F(A_t, K_t, L_t)}{\partial K_t} = R_t \quad (3.1.9)$$

and:

$$P_t \cdot \frac{\partial F(A_t, K_t, L_t)}{\partial L_t} = \omega_t \quad (3.1.10)$$

Now, as there are constant returns to scale and the production function is homogeneous to degree one in K_t and L_t , the Euler theorem applies and we have:

$$F(A_t, K_t, L_t) = \frac{\partial F(A_t, K_t, L_t)}{\partial K_t} \cdot K_t + \frac{\partial F(A_t, K_t, L_t)}{\partial L_t} \cdot L_t \quad (3.1.11)$$

By also using equations 3.1.9 and 3.1.10 in equation 3.1.11, we immediately see that in this model firms do not make profit:

$$P_t \cdot Y_t = R_t \cdot K_t + \omega_t \cdot L_t \quad (3.1.12)$$

and that (by solving also for K_t and L_t) the shares of labor, S_{L_t} , and capital, S_{K_t} , in national income, are stable (and actually constant in the Cobb-Douglas case), in accordance with the Kaldor fifth stylized fact above:

$$S_{K_t} = \alpha = \frac{R_t \cdot K_t}{P_t \cdot Y_t} \quad (3.1.13)$$

$$S_{L_t} = 1 - \alpha = \frac{\omega_t \cdot L_t}{P_t \cdot Y_t} \quad (3.1.14)$$

Assuming now that all the markets clear, that we have no government and that we are in a closed economy, then in the model all the final output Y_t is used for final consumption (C_t) and firms' investment (I_t) and we necessarily have:

$$Y_t = C_t + I_t \quad (3.1.15)$$

with also:

$$S_t = I_t = Y_t - C_t \quad (3.1.16)$$

that is to say, that savings, S_t , always equate the investment.

Furthermore, in the model, households are assumed to save a constant fraction of their revenues, s , then:

$$S_t = s \cdot Y_t \quad (3.1.17)$$

and:

$$C_t = (1 - s) \cdot Y_t \quad (3.1.18)$$

By combining equations 3.1.1, 3.1.4 and 3.1.17 we finally obtain the famous “*fundamental law of motion*” of the Solow model:

$$\Delta K_t = s \cdot F(A_t, K_t, L_t) - \delta \cdot K_{t-1} \quad (3.1.19)$$

that is generally expressed in efficiency units of labor⁵, so we get:

$$\Delta k_t = s \cdot f(k_t) - (\delta + n + g) \cdot k_{t-1} \quad (3.1.20)$$

where small letters mean that the corresponding variable, or function, has been divided by $A_t \cdot L_t$.

3.1.4 Transitional dynamics and convergence towards the balanced growth path

This non-linear differential equation tells us that three different forces influence the evolution of capital per efficiency units of labor (k_t), that are represented on the figure 3.1.1:

1. The rate at which new savings rise k_t : $s \cdot f(k_t) = s \cdot k_t^\alpha$;
2. The rate at which depreciation causes k_t to fall: $\delta \cdot k_{t-1}$;
3. The rate of growth of labor efficiency units that reduce proportionally k_t (dilution effect): $(n + g) \cdot k_{t-1}$

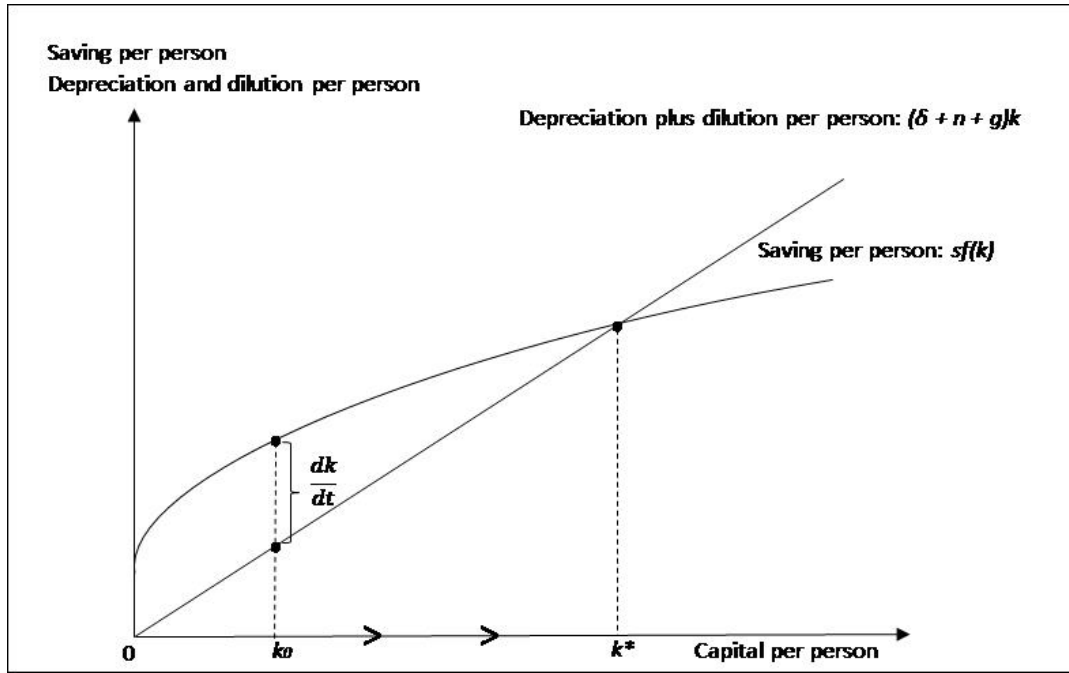
The law of diminishing returns implies that the saving curve is concave on the graph, while the effects of depreciation and of the growth of the number of efficiency units are represented on the straight line passing by the origin. Given any initial stock of capital per efficiency unit of labor k , where savings are superior to depreciation plus the dilution effect (k_0 point on figure 3.1.1), then the capital stock will increase by the difference between the saving curve and the depreciation line. And capital per efficiency unit of labor will continue to increase until its long run level,

$$k_t^* = \left(\frac{s}{\delta + n + g} \right)^{\frac{1}{1-\alpha}} \quad (3.1.21)$$

will be reached, that is the unique and stable steady state for k_t .

⁵Still assuming that the technical progress is Harrod neutral, as in equation 3.1.5.

Figure 3.1.1 – Convergence to the study state in the Solow model



Source: Adapted from Aghion and Howitt, 2009 ([9]).

Note that if k_t , the capital stock per unit of efficiency units of labor, reaches a steady state in the long run, it will not be the case for the output per person, $\frac{Y_t}{L_t} = A_t \cdot k_t^\alpha$, for which the growth rate, similarly to Aghion and Howitt (2009, [9], ch. 1, P. 29), can be written:

$$G_t = \frac{\Delta A_t}{A_{t-1}} + \alpha \cdot \frac{\Delta k_t}{k_{t-1}} = g + \alpha \cdot \frac{\Delta k_t}{k_{t-1}} \quad (3.1.22)$$

Therefore we see, as Aghion and Howitt explain (*ibid*), that as k_t approaches k_t^* , the growth rate of GDP per *capita* will progressively converge toward the exogenous rate of technical change, g . We also see that without technical change, that allows to fight against the law of diminishing returns to capital in the model, there is no growth of output per capital in the economy. As investment and final consumption are a fixed proportion of national income in the model, capital per *capita*, $\frac{K_t}{L_t}$, and consumption per *capita*, $\frac{C_t}{L_t}$, will grow at the rate of exogenous technical progress, g , conforming to the second Kaldor fact listed above. All the variables, national income, capital stock and final consumption will therefore grow at the same exogenous rate in the model; that is, the sum of the exogenous growth rates of population and of technology. Then we have the following balanced growth path (BGP hereafter):

$$\frac{\Delta Y_t}{Y_{t-1}} = \frac{\Delta K_t}{K_{t-1}} = \frac{\Delta C_t}{C_{t-1}} = n + g \quad (3.1.23)$$

The main implication is that at the steady state growth rate equilibrium, the capital to output ratio will remain stable over time, like for the Kaldor's fourth stylized fact, which is compatible also with Kaldor's third stylized fact: returns to capital, real interest rates, have been relatively stable over time.

3.1.5 Implications for convergence of GDP per capita in different countries

The last important feature of Solow's model is finally the strong implications it has for the convergence of GDP per *capita* in different countries. We see, from the expression of the steady state level of capital per efficiency unit of labor, given by equation 3.1.21 above, that if the different countries in the world have the same set of structural parameters, $\theta = (\alpha, s, \delta, n, g)$, they will all converge toward the same level of capital per efficiency unit of labor, k^* . For example, as stated again by Kaldor in his sixth stylized fact, if a country initially has a weekly level of k , the fundamental law of motion of capital per efficiency unit of labor implies from equation 3.1.22 above, that it will grow faster than a country that already reached its steady state. The model therefore predicts that the level of GDP per *capita* in the poorest and less developed countries should converge at the same level of GDP per capital as in the richest and more developed countries. This type of convergence is known as conditional convergence, as it is conditional to the assumption that all countries have the same set of structural parameters, θ , and fundamental characteristics.

In reality, the data on national accounts show; using cross-country comparisons from the 50s up to 70s; at once considerable differences in the level of income per capita and in the growth rate of income, The countries with the lowest initial level of income per capita also have the highest growth rates. It demonstrates the influence of transitional dynamics in the model, when k moves progressively to k^* , that explains why the growth rates are not constant in time, and why various countries progressively change their position in the world income distribution.

Let's now test these assumptions econometrically. The survey of the empirical literature by Islam (2003, [170]) shows that the conclusions of the Solow's model on convergence must be nuanced. Studies that bear on a large sample of countries, such as Baumol (1986, [21]) using the data set of Maddison (1982, [227]) for 72 countries from 1870-1979, tend to show a convergence between industrialized countries, and between industrialized and "*planned economies*", but not with less developed countries.

This result led Baumol (*ibid*) to introduce the concept of “*Club-convergence*”, meaning that only countries that share some common attributes or an initial position on the level of per *capita* income, will converge. For example, Barro and Sala-i-Martin (1992, [20]) found strong evidence of convergence across US States during the period 1840-1963. Therefore for Islam (1995, [171]), but also for Barro and Sala-i-Martin (1992, *ibid*) and for Mankiw, Romer and Weil (1992, [231]), what the Solow-Swan model predicts is not a convergence of all countries towards the same level of GDP per *capita*, but rather that each country, or “*club*” of countries, will reach its own steady state.

To summarize, the neoclassical model of growth predicts that the countries sharing similar characteristics, and notably, from equation 3.1.23, having the same rate of technological progress, would in the long term reach the same growth rate of GDP per *capita*, rather than the same level of GDP per *capita*. For Islam (2003, *ibid*, P. 341), “(...) *the welfare implication of the conditional convergence finding*” is therefore rather limited, and the “(...) *agreement about estimated values of growth models, such as the rate of convergence and the elasticity of output with capital, has proved elusive*” (Islam, *ibid*, P. 341). Convergence rates notably appear much higher when allowing for technological differences (g value) between countries, as in Mankiw, Romer and Weil (1992, *ibid*). Mankiw, Romer and Weil also show that, the excessively high values generally found for output elasticities (α) in the studies, imply that the notion of capital in them must be understood in a much broader sense than simply physical capital, and the inclusion of human capital in the production function considerably reduces the estimated value of output elasticities.

3.1.6 What finally is the true engine for growth: Capital deepening or technological externalities?

Finally, from the literature on convergence, we could conclude that it is more important to look at the determinants of long run steady state growth rates, rather than at transitional dynamics. What appears, from equation 3.1.23, is that in the long run, once the level of capital per efficiency unit of labor has reached its steady state value, k^* , the only source of growth that subsists is the exogenous rate of technological progress, g . For growth accounting literature, the problematic is therefore to decompose the growth of output per *capita* between these two components: the rate of technological progress, or of technological externalities, g , and the rate of capital deepening, $\alpha \cdot \frac{\Delta k_t}{k_{t-1}}$. But in a neoclassical growth model, there is no capital deepening without growth of technological externalities, that fights against the law of decreasing marginal returns to capital. So, is it technological progress

that causes capital accumulation, as first investigated by the AK models, or is it capital accumulation that provokes technological progress?

Before beginning to analyze this question in the next section, we must finally underline that in the Solow-Swan model we just presented, the saving rate, s , is exogenous. As Aghion and Howitt (2009, *ibid*, P. 31 and following) stressed, the model, like in the preceding Harrod-Domar model, lacks explicit micro-foundations. It focuses on the production side, and the firms' optimum, in this context taking the saving rate as exogenous “(...) *is not a bad approximation to reality. But [on the consumer side] many writers believe that the subtleties of the permanent income and life-cycle savings hypotheses should be taken into account, on the grounds that people save with a view of smoothing their consumption over their lifetimes, taking into account their preferences for consumption at different dates and the rate of return that they can anticipate if they sacrifice current consumption in order to save for the future*”. By introducing these additional ingredients into the Solow-Swan model, from the original contribution of Ramsey (1928, [275]), Cass (1965, [53]) and Koopmans (1965, [196]) a model appears finally where the saving rate is endogenous, and where the decentralized equilibrium can be compared to the Pareto efficient one. At the equilibrium, the main difference with the Solow-Swan model, is that the savings rate, and consequently the level of capital per worker, are inferior, because households discount for future utility and consumption in the RCK model, and then save less. This property also ensures that, in the long run, the value of capital will not grow faster than the rate of time preference, which would reduce the value of households inter-temporal utility function. Anyway, it does not change the major conclusions of the Solow-Swan model on the importance of capital accumulation and technological progress, and on the convergence towards a balanced growth path. This is the framework that all the models aimed at endogenizing technical progress, that are presented in the next sections, use.

3.2 The AK models

The capacity of the Solow-Swan model to reproduce Kaldor's six stylized facts has certainly represented an important improvement compared to the previous Harrod-Domar model. The use of the Cobb-Douglas production function and the introduction of exogenous technical progress have therefore permitted a description of BGP with full employment, and a decentralized equilibrium compatible with the Pareto optimum, as synthesized by the RCK model. When doing this, the first applications of the model using national accounting data for the United States were quite disturbing. Solow therefore

concluded in his pioneering growth accounting work for the United States published in 1957 ([301])⁶, “*Technical Change and the Aggregate Production Function*”, that “(...) from a crude application [of its 1956’s model] to American data, on 1909-49, (...) gross output per man hour doubled over the interval, with 87.5 per cent of the increase attributable to technical change and the remaining 12.5 per cent to increased use of capital” (Solow, *ibid*, P.3 20). Similar findings by Abramovitz (1956, [1]) on the longer time period from 1869-1953 forced him to make the famous statement: “*Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth in the United States and some sort of indication of where we need to concentrate our attention*” (Abramovitz, *ibid*, P. 11).

Therefore, in Solow’s neoclassical growth model, for the most part, if not all, once capital per efficiency unit of labor has reached its optimum, the growth of GDP per *capita* is attributed to exogenous productivity increase, that can occur independently from capital accumulation. The model, contrary to Harrod-Domar’s Keynesian growth model⁶, succeeded in describing the important rise of GDP per capita that was observed from the beginning of the industrial revolution; but it could not “*explain*” this rise apart from the influence of exogenous forces, that consequently could not be influenced by economic policy. This situation was quite unsatisfactory and it led two authors, in two 1962 articles, to reintroduce the role played by investment in the economic growth process.

On the one hand, there is the article by Arrow (1962, [15]), that introduces “*learning by doing*” into the Harrod-Domar model, with new capital goods having higher productivity than older ones, using past experience acquired in producing capital goods, and with “(...) *cumulative gross investment (cumulative production of capital goods) as an index of experience*” (Arrow, *ibid*, P. 157). The learning process is such that it is compatible with a steady rate of growth of both labor and capital productivity.

⁶Contrary to the Solow model, the Harrod-Domar model assumes constant labor and capital marginal productivity and capital to output ratios. In this model, the production function for final output is therefore of a Leontieff type, such as:

$$Y_t = F(K_t, L_t) = \min \{A \cdot K_t, B \cdot L_t\} \quad (3.2.1)$$

where A and B are fixed coefficients. If $A \cdot K_t > B \cdot L_t$, $Y_t = B \cdot L_t$, the growth of output per capita is limited by the growth of population, and there are inflationary pressures. On the contrary, where $A \cdot K_t < B \cdot L_t$, and $Y_t = A \cdot K_t$, in the case privileged by Harrod and Domar, the growth of output is limited by the growth of capital accumulation and there is unemployment. Then we assume, like in the Solow model, that the population grows at the exogenous rate n and that the saving rate, s , is constant, and we have $\frac{\Delta Y_t}{Y_{t-1}} = \frac{\Delta K_t}{K_{t-1}} = \frac{\Delta C_t}{C_{t-1}}$, final output, capital, final consumption, where all the variables grow at the same rate. But in the first case ($Y_t = B \cdot L_t$), when labour is the limiting factor, the growth rate of capital and output equates the one of population, n . In this case, there is no capital deepening, and no growth of output per capita. In the opposite case ($Y_t = A \cdot K_t$), when capital accumulation is the limiting factor, a rise in the saving rate would raise output growth, and the level of capital and consumption per capita, with a decrease in unemployment. We see that the model is characterized by instability that requires policy intervention for fighting unemployment or inflationary pressures.

On the other hand, Frankel (1962, [125]) introduced a distinction between the individual production function of firms, as in the Solow model of Cobb-Douglas type, and the aggregate production function that admits an AK representation. In this model, the individual increase in productivity comes from a collective externality that originates from the accumulation of capital by unit of labor, by individual firms. Whereas at the aggregate level, the growth of output per *capita* comes only from capital accumulation and from the externalities that firms send one another. It can be interpreted as a special case of the Cobb-Douglas production function, where the coefficient capital, α , equals 1, and the labor coefficient, $1 - \alpha$, 0; or, alternatively as a special case of the production function of the Harrod-Domar model, where the labor coefficient, B , equals 0.

These two initial models, by Arrow (1962, [15]) and Frankel (1962, [125]), were finally popularized by Romer ([283]) in his famous 1986 paper, “*Increasing Returns and Long-Run Growth*”, that synthesizes these two previous approaches within the initial setting of the RCK model.

3.2.1 The central distinction between internal and external returns in the original AK model introduced by Frankel in 1962

The idea followed by Romer, in his 1986 article, was to introduce increasing returns to scale in the neoclassical model of growth, like in the exogenous technical progress imagined by Solow and Swan, but within a framework where it results from endogenous decisions by economic agents, but remains at the same time compatible with the stable, competitive and decentralized equilibrium of the RCK model.

To do this, Romer starts with the distinction, first introduced by the works of Alfred Marshall, in his “*Principles of Economics*”, published in 1890, between “*internal*” and “*external*” returns. Marshall made this distinction by observing the tendency of different manufacturers in Great Britain to form geographical clusters of industries, to benefit from external effects such as easier recruitment of skilled labor, fast circulation of commercial and technical information through informal channels, that all allowed important reductions in transaction and operating costs. Whereas, inside a cluster or an industry, the manufacturers or firms were highly competitive and producing with constant returns to scale technologies, the positive externalities between the different firms was at the origin of increasing returns at the industry level.

In this distinction between “*internal*” and “*external*” returns, we can recognize easily, even if Romer did not refer to it, the framework that Frankel described (*idib*), where individual firms have an “*ex*

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ante” constant return to scale technologies, at the time they take their production decisions and of use of factors, but their ex post “*realized*” production function moves upwards with the influence of “(...) *modifier shifts*. *The shifts are exogenous for the enterprise in question and reflect the collective impact of the actions of all enterprises as they respond in similar fashion to economic opportunities*”.

More precisely, Frankel uses a Cobb-Douglas setting, where individual firms have a production function of the form:

$$y_{it} = A \cdot H_t \cdot k_{it}^\alpha \cdot l_{it}^{1-\alpha}$$

where A is a constant, k_{it} and l_{it} ; respectively, the capital and the labor employed by the firm i , and H_t is what Frankel calls the “*modifier*”. This “*modifier*”, that in the model plays the role of the exogenous technical change in the Solow model, is for Frankel (P. 998) “(...) *the level of development of the economy in which the enterprise operates and is, for the enterprise, a parameter*”. For Frankel, this setting reflects the “*essence of economic development*”, as “*Enterprises in relatively developed or advanced economies are able to produce more with given inputs of capital and labor than enterprises in relatively under-developed countries*” (Frankel, *ibid*, P. 998).

The aggregate output is then obtained by supposing that a “*typical*” enterprise produces $\frac{1}{N}$ th of the total output, and we obtain:

$$Y_t = N \cdot y_{it} = A \cdot H_t \cdot k_{it}^\alpha \cdot l_{it}^{1-\alpha}. \quad (3.2.2)$$

As furthermore all firms are identical, the total quantities of labor and capital used in the economy are:

$$K_t = N \cdot k_{it} \quad (3.2.3)$$

and:

$$L_t = N \cdot l_{it} \quad (3.2.4)$$

which gives the aggregate production function:

$$Y_t = A \cdot H_t \cdot K_t^\alpha \cdot L_t^{1-\alpha}. \quad (3.2.5)$$

It now only remains for Frankel to explain the expression of the “*modifier*”, H_t . Frankel (*ibid*, P.

999) explains that it could be any variable linked to the level of development, such as “(...) *birth or death rates, literacy rates, nutritional levels, levels of per capita income, or levels of capital per worker*”.

Choosing the latter, we have:

$$H_t = \left(\frac{K_t}{L_t} \right)^\gamma \quad (3.2.6)$$

with the parameter γ “*give(ing) the expression a more general form*”.

If H_t is a “*parameter*” at the level of an individual firm, it is a “*variable*” for the entire economy, and by replacing it in the production function, we finally get:

$$Y_t = A \cdot K_t^{\alpha+\gamma} \cdot L_t^{1-\alpha-\gamma} \quad (3.2.7)$$

The most striking case, investigated by Frankel, appears in this special case where $\gamma = 1 - \alpha$, which implies that the production function reduces to:

$$Y_t = A \cdot K_t \quad (3.2.8)$$

which provides the first expression of the *AK* model, where production at the aggregate level seems to be the outcome of the use and the accumulation of capital alone. To quote Frankel (*ibid*, P. 1000), “*The upshot is that instead of moving along its production function (3.2.2), $y_{it} = A \cdot H_t \cdot k_{it}^\alpha \cdot l_{it}^{1-\alpha}$, which is an ex ante function, the enterprise moves along a realized function which mirrors (3.2.8), namely $y_{it} = A \cdot k_{it}$* ”.

Therefore, if one interprets the “*modifier*” as a variable that internalizes “*all of the effects on development that are collectively generated by enterprises (...) improvements in organization and the quality of labor, technical change, external economies of scale, and better social overhead facilities in the form of transport and communication networks, [that can be summed-up into some measure of the aggregate capital stock], (...) a one-factor production function like $Y_t = A \cdot K_t$ may be entirely appropriate and in itself carry no necessary implication, long- or short-run, about the scope of factor substitution and, in so far it may be related to factor substitution, the equilibrium of the system*” (Frankel, P. 1001).

Finally, as Aghion and Howitt comment (1998, [9], P. 49), while Frankel “(...) *was motivated by the challenge of constructing a model that could combine the virtues of the Solow-Swan [the stability of*

the relative contribution of labor and capital for economic growth] and the Harrod-Domar model [the higher role attributed to investment for explaining the long term growth]”, is doing that, the AK model he introduces, that can be interpreted as the Harrod-Domar model without labor coefficient, suffers from similar “knife-edge” effects. Three cases occur, depending the values of the parameters α and γ :

- If $\alpha + \gamma < 1$, the strength of knowledge externalities is too low to compensate for the marginal decreasing returns to capital at the level of the individual firms $(1 - \alpha)$ and the long-run growth rate is 0;
- If $\alpha + \gamma > 1$, the knowledge externalities are too strong and the long-run growth rate will increase continuously in time, becoming explosive;
- If $\alpha + \gamma = 1$, we are in the “knife-edge” case, where the knowledge externalities exactly compensate the marginal decreasing returns. This is the AK case, compatible with full employment and a BGP where the level of income per *capita* increases at the constant steady rate g .

3.2.2 Arrow’s 1962 model and “The Economic Implications of Learning by Doing”

The second important early attempt for endogenizing technical change, to which Romer refers in his famous 1986 paper, was realized by Arrow (1962, [15]) with the introduction of the concept of learning by doing. In Arrow’s model, while there is no substitution between labor and capital, that are used in fixed proportions, the quantity of output per unit of labor that can be produced increases at a constant rate in time from “learning by doing”, that he measures by “ G ”, that is an index of all past accumulated production of capital goods. As Arrow explains, “Each new machine produced and put in use is capable of changing the environment in which production takes place, so that leaning is taking place with continuous new stimuli. This at least makes the possibility of continued learning plausible in the sense, here, of a steady rate of growth of productivity”.

To be more explicit, in Arrow’s model, learning by doing increases the stock of knowledge that is an externality in the production function of individual firms. It is measured by cumulative gross investment, such as:

$$K_t = \sum_{v=-\infty}^t I_v, \quad (3.2.9)$$

with K_t the stock of knowledge and I_t , the gross investment. As production is made with fixed

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proportions of labor and capital, the production, $Q_{t,t}$, associated to the new generation of capital goods, t , is such that: $Q_{t,t} = a \cdot I_t$. This is a “*special case*” that Arrow favors, where the output to capital ratio is constant over time.

The corresponding quantity of labor is given by

$$L_{t,t} = b \cdot K_t^{-\gamma} \cdot I_t, \quad (3.2.10)$$

with $\gamma > 0$. This is this time a decreasing function of the stock of knowledge, and the technical progress is labor saving. It follows that by replacing this latter equation in the equation for final output, that:

$$Q_{t,t} = \frac{a}{b} \cdot K_t^\gamma \cdot L_{t,t}. \quad (3.2.11)$$

We therefore see from equation 3.2.11 above, that the Arrow model accepts, like the Frankel model, an AK representation, by assuming $\gamma = 1$.

Then, on a balanced growth path, with a constant length of life of the different generations of equipments, Q and K grow at the same rate g , and L grows at the exogenous rate, n . As d’Authume and Michel explain (1993, [89]):

- In the case where $\gamma < 1$, the long term growth rate does not depend on saving behavior, and it is bounded by the growth rate of population, like that Romer describes on the page 1006 of his 1986 paper: “*As a result, the rate of growth of output is limited by the rate of growth of the labor force*”;
- Now, if $\gamma = 1$, d’Authume and Michel show (*ibid*) that the model this time provides an endogenously determined growth rate of aggregate output. It expresses: $g = s \cdot a \cdot \left(1 - e^{-\frac{t}{b}}\right)$, with s , the savings rate. We see that there is a size effect, but that it is bounded and tends to zero as population increases;
- In the last case where $\gamma > 1$, one should expect an explosive growth rate, but “*This does not materialize, however, as the constant technical coefficient of capital puts an upper bound on the growth rate*” (d’Authume and Michel, *ibid*, P. 1177). As in the case where $\gamma = 1$, it will rather tend to $s \cdot a$ as t tends to infinity.

Therefore, in the Arrow model, endogenous growth will occur “*whenever $\gamma \geq 1$* ”. In other words, the

value of γ must be strong enough in order to compensate for the constancy of the capital coefficient in time. We see also that the “*knife-edge*” effects in the model are less important than in the previous Frankel model.

3.2.3 Romer’s 1986 paper

Similarly to the ideas developed by Frankel, Romer (1986, [283]) considers N identical firms indexed by i , that have the following production function:

$$y_{it} = f_{it}(k_{it}, K_t, x_{it}) \quad (3.2.12)$$

where k_i is the private stock of knowledge of the firm, x_i a set of additional factors “*such as physical capital, labor, and so forth*”, and, $K_t = \sum_{i=1}^N k_{it}$, is the aggregate stock of knowledge. Contrary to Frankel, where it is not clear if K is a measure of physical capital or a compound of physical capital, knowledge and the accumulation of other factors such as public infrastructures, Romer assumes that K is totally disembodied and measures the accumulation of knowledge over time. New knowledge can be assimilated with the invention of new ideas for combining the set of ordinary production factors x_{it} . Then, in the model, Romer explains that “*The creation of new knowledge by one firm is assumed to have a positive external effect on the production possibilities of other firms, because knowledge cannot be perfectly patented or kept secret*” (Romer, *ibid*, P. 1003). The last feature of the model is that new knowledge, Δk , is produced in-house by the firm from investment in research, r , and past accumulated private knowledge, k , and we have:

$$\Delta k_{it} = g_{it}(r_{it}, k_{it-1}) \quad (3.2.13)$$

where the investment in research, r , is composed of forgone consumption.

The production function for new knowledge, $g(\cdot)$, is supposed to have constant returns in r and k , where the firm faces diminishing returns from research investment, for a given level of k . Also, similarly to Frankel (1962), but with x replacing l , the production function for the final output of the individual firm, $f(\cdot)$ is assumed to be homogeneous to degree 1 as a function of k and x , and to be concave in k and x , for a fixed level of K . Exactly as in Frankel (1982), it exhibits globally increasing returns from the influence of the aggregate knowledge externality K alone. K therefore plays exactly the same role than the “*modifier*” of Frankel, in the Romer model .

To analyze more closely what distinguishes Romer's from the Frankel model, we suppose that the production function of the final output of an individual firm is the same as in Frankel (1962, [125]):

$$y_{it} = A \cdot H_t \cdot k_{it}^\alpha \cdot x_{it}^{1-\alpha} \quad (3.2.14)$$

where we suppose that H , the "modifier" of the Frankel model, this time admits the following expression:

$$H_t = K_t^\gamma \quad (3.2.15)$$

and is now only a function of the "natural" externalities that arise from the impossibility for private firms to keep the new knowledge they produce secret for long. So by aggregating over various firms we obtain:

$$Y_t = A \cdot K_t^{\alpha+\gamma} \cdot X_t^{1-\alpha-\gamma} \quad (3.2.16)$$

with $X_t = \sum_{i=1}^N x_{it}$, the aggregate stock of ordinary production factors. If we furthermore assume to simplify, as Romer does, that X , as the labor force, does not grow, and retain the special case where $\gamma = 1 - \alpha$, then we get the same AK function as Frankel above (equation 3.2.8), with $Y_t = A \cdot K_t$.

The novelty with Romer, compared to Frankel, is that we have now also a production function for new ideas, or new knowledge, $g(\cdot)$, that, from Romer's description, we can also assume to be a Cobb-Douglas type, such as for example:

$$\Delta k_{it} = B \cdot k_{it-1}^{\beta_k} \cdot r_{it}^{\beta_r} \quad (3.2.17)$$

with B , β_k and β_r , positive parameters. We see that with this specification of the g function, learning by doing results using the experience acquired by the firm from its past private investments in research, r , and production of new knowledge, k . It is therefore more restrictive than in Arrow (1962, [15]) where learning by doing results from cumulative gross investment by all the firms. Then, by aggregating over firms, we get a similar expression for the aggregate production of new knowledge:

$$\Delta K_t = G_t(R_t, K_{t-1}) = B \cdot K_{t-1}^{\beta_k} \cdot R_t^{\beta_r} \quad (3.2.18)$$

with $\Delta K_t = \sum_{i=1}^N \Delta k_{it}$, $K_{t-1} = \sum_{i=1}^N k_{it-1}$ and $R_t = \sum_{i=1}^N r_{it}$.

To avoid increasing returns to scale at the level of the individual firm, Romer supposes that $g(\cdot)$ has constant returns to scale on k and r , which is expressed in our setting by $\beta_k + \beta_r = 1$. The consequence is, finally, like in the Frankel model, that the only source of externalities arises from the production function for final output, from the inter-temporal unintentional externality from capital accumulation, measured through the variable H_t . This is the reason why the two models look so similar, sharing the same AK reduced form.

Therefore, the introduction of learning by doing in the model, does not seem to play any role, and we get exactly the same expression for the growth rate of output as in Frankel (1962), where the accumulation of capital follows the usual accumulation rule obtained by equating savings to investment. The only difference is that in Romer, we have the two fundamental elements for representing the sources of endogenous growth, that we will find in the next section, when presenting the first generation of endogenous growth models: inter-temporal knowledge externalities, and investment in research by private firms.

To anticipate the presentation of the properties of these latter models, Romer could have introduced the “*modifier*” $H_t = K_t^\gamma$ in the g function too, so we get:

$$\Delta k_{it} = B \cdot H_t \cdot k_{it-1}^{\beta_k} \cdot r_{it}^{\beta_r} = B \cdot K_t^\gamma \cdot k_{it-1}^{\beta_k} \cdot r_{it}^{\beta_r} \quad (3.2.19)$$

Then by aggregating over firms, and by assuming furthermore that $\gamma + \beta_k = 1$, we get the expression of the increase in the aggregate knowledge:

$$\Delta K_t = G_t(R_t, K_{t-1}) = B \cdot K_{t-1} \cdot R_t^{\beta_r} \quad (3.2.20)$$

that is finally very close to the reduced form that appears, at the aggregate level, in the first generation of endogenous growth models. Romer proposed in 1990 ([284]), the first of these models where endogenous growth finally comes from the new knowledge arising from inter-temporal knowledge externality resulting from past discoveries and past investments in research by all firms, as in equation 3.2.20. This growth engine finally pushes up the growth of output per *capita*, from the AK -type aggregate production function for final output. The introduction of knowledge externalities in the innovation process is therefore closely related to the introduction of increasing returns to scale in the production function.

Finally, if the first *AK* model was created by Frankel (1962, [125]) and Arrow (1962, [15]), the Romer (1986, [283]) and Lucas⁷ (1988, [225]) models are still considered the pioneering works of the neoclassical endogenous growth theory, where the savings rate results from the individual intertemporal utility maximization à la Ramsey of the RCK model.

3.2.4 The implications for convergence and economic policy

As Aghion and Howitt explain (2009 *ibid*, P. 13), “*AK models do not make a clear distinction between capital accumulation and technological progress. In effect they just lump together the physical and human capital whose accumulation is studied by the neoclassical theory with the intellectual capital that is accumulated when technological progress is made. When this aggregate of different kinds of capital is accumulated, there is no reason to think that diminishing returns will drag its marginal product to zero, because part of the accumulation is the very technological progress that is needed to counteract diminishing returns*”. The *AK* model is therefore a “*neoclassical model without diminishing returns*”, and the best way to stimulate growth is “*to save a large fraction of GDP, some of which will find its way into financing a higher rate of technological progress and will thus result in faster growth*”. This new framework notably allowed Rebelo (1991, [278]) to study the impact of public fiscal policies on long term growth.

As a consequence, and to once again take the words of Aghion and Howitt (2009, *ibid*, P. 14), the *AK* model is a “*one-size-fits-all*” model, that “*(...) applies equally to advanced countries that have already accumulated capital and to countries that are far behind*”. The model does not predict any convergence on the level of GDP per *capita*. On the contrary, the model predicts that the level of income per *capita* in the different countries should exhibit “*both absolute and conditional divergence*” (Aghion and Howitt, *ibid*, P. 56). The model also predicts that the economic development in one country is independent of the development in the rest of the world, and that it is better to invest locally to benefit from the externalities arising from capital accumulation. The model does not, consequently, provide a convincing explanation for convergence from the fact that “*it does not make an explicit distinction between capital accumulation and technological progress*” (Aghion and Howitt, *ibid*, P. 66). For convergence, we will see in the next sections that the innovation-based NGT theory models, that

⁷There we do not describe the model by Lucas that, inspired by the theory of Human Capital developed by Becker (1964, [25]), assumes that investing in knowledge creation was similar to investing in human capital, creating similar knowledge externalities that take the form of public learning.

make this distinction clear between capital accumulation and technological knowledge, do better for “*fitting the data with long-run growth and convergence*”, thanks notably to the introduction of the role played by international knowledge spillovers, and the notion of distance to the technological frontier.

The most important consequence of the *AK* models, and the introduction of increasing returns from externalities in the neoclassical model of growth, is certainly that the decentralized equilibrium of the economy is not equivalent anymore to the Pareto social optimum, as was demonstrated by Romer (1986, [283]) and Lucas (1988, [225]). Today investors benefit from investments in knowledge realized in the past for free, and also of those made currently by other firms or individuals. This introduces a distortion between private and social returns, and the impossibility to fully appropriate the returns from its own investments in knowledge, leading to private agents systematically under-investing compared to what would be socially optimum. It leads to the conclusion that the decentralized market equilibrium is sub-optimal, and that public intervention is necessary to stimulate investment in knowledge creation at the source of the endogenous growth. With this conclusion, consequently we are far from the original optimism expressed by the RCK model and the belief that the decentralized actions of the agents would bring the economy towards its long term social optimum, and a stable long-run BGP.

But, as Romer (1990, [284]) wrote himself about *AK* models and the generation of knowledge capital in them, they “(...) *make the production of a non rival, non excludable good an unintentional side effect of the production of a conventional good*” (Romer, 1990, page S76). They preserve the intrinsic “*public good characteristic*” of technology of the Solow model, but in doing that, they do not explicitly represent the motivation for investing in technology, by introducing market power, like the NGT models presented in the next section.

3.3 The first generation of NGT models

The pioneering models by Romer (1986, [283]) and Lucas (1988, [225]) are one sector, one good, models. They do not have any separate sectors, such as a research sector, where the production of technological knowledge would result from explicit micro foundations, and competition for monopoly rents and market power. It is this improvement that resulted in the “*First generation of endogenous growth models*” by (Romer, 1990, [284]), Grossman and Helpman (1991, [152]) and Aghion and Howitt (1992, [4]). For that, as Verspagen explained (1992, [326]), they introduced a clear distinction between general scientific and technological knowledge on the one hand, and blueprints or technological innovations on

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the other hand. This general knowledge is not appropriable (or excludable) by firms in the research sector, and flows from one innovator to the other. It can be seen as a by-product of innovation activity. On the contrary, blueprints or innovations resulting from investments in research, and the accumulation of specific technological knowledge, can be totally appropriated, for example by the means of an infinite life patent, the producer of the patent becomes a monopolist, or an oligopolist depending the type of innovation and the market structure. *“Thus, the problem of lack of incentives to produce technological change in the presence of public good features is solved by making the distinction between general technological knowledge (non-appropriable) and specific technological knowledge (appropriable)”*. (Verspagen, *ibid*, page 641).

NGT models are therefore generally three sector models with:

1. A competitive research sector, with free entry, where the production of new ideas results from investment in research, where productivity is pushed-up by the accumulation of general knowledge resulting from the past innovations by all innovators;
2. An intermediate sector, buying new ideas from the research sector, that they transform into marketable innovations providing them a monopoly rent with the protection of an infinite life patent;
3. A final good sector, with pure and perfect competition, where the productivity increases following the improvement of the set of intermediate inputs that is available for producing the final output, similarly to the action of the exogenous technical progress in the Solow model, or to unintentional knowledge externalities arising from capital accumulation in the AK models.

The first generation of NGT models that appeared in the early 1990s, belonged to two groups, depending the type of innovation they represent:

1. Firstly, the product variety model, introduced by Romer (1990, [284]), where innovations reflect the introduction of new brands, or new product varieties, on the market. It is a model of horizontal innovation, that builds on the original model of monopolistic competition by Ethier⁸ (1982, [114]) in the context of international trade theory, with the idea that increasing returns result, like in *“Adam Smith’s pin factory”* (Ethier, *ibid*), from the division of labor between

⁸Ethier bases himself his model on the Utility function proposed by Dixit and Stiglitz (1977, [102]) to represent a preference for variety (*“Love-for-variety”*), that he reinterprets as a production function where output is an increasing function of the number of specialized intermediate inputs that are used in production).

an increasing variety of activities. Romer (1990, *ibid*) extended this framework, making this specialization the results of research efforts by profit-seeking firms or individuals. Here, the endogenous growth rate of the economy is proportional to the number of new varieties that are created.

2. Then there is also the Schumpeterian model, developed by Grossman and Helpman (1991, [152]), and by Aghion and Howitt (1992, [4]), where this time innovations take the form of gradual quality improvements in a fix set of old products by innovators. It is a model of vertical innovation, that was inspired this time by the modern theory of industrial organization and the patent-race models developed by Tirole (1988, chapter 10, [238]) and Reinganum (1989 [279])⁹. The main novelty of this “*quality ladder*” model, is to have translated the previous static and partial equilibrium setting into an inter-temporal and general equilibrium, of the optimal growth models. Here, the endogenous growth rate of the economy is proportional to the average quality improvement of the intermediate goods that are used to produce the final output.

We see that horizontal and vertical differentiation models complement each other on the type of innovation they represent. They differ, and also complement each other, on the type of competition they describe. In the product variety model, a new monopoly is created each time a new variety of product is introduced, and old monopolies are not displaced by the new ones. The price setting follows the standard rule of the oligopoly competition, with a constant margin over marginal cost. New firms enter but old firms remain. On the contrary, in the Schumpeterian model of innovation, the entrant firms that improve the old products, displace the incumbent ones. Competition is based on the “*Creative-Destruction*” concept, that was introduced by Schumpeter (1942, [294]), and on the perpetual “*turnover*” of firms. In this model, the price setting is based on “*limit pricing*” as described by Grossman and Helpman (1991, [152]), with the price of the new product just above the price of the old one, ensuring that the entrant firm takes all the market of the product. This “*business stealing*” effect in the Schumpeterian model, that represents a negative externality, therefore implies that too many resources may be invested in research, compared to what would be socially optimal. On the contrary, in the product variety model, like the previous *AK* models, with only positive inter-temporal knowledge externality, is present, the level of resources that are spontaneously invested in research will

⁹These authors were themselves influenced by the seminal works on patent’ races by Loury (1979, [224]), Dagupsa and Stiglitz (1980, [86]) and Lee and Wilde (1980, [213]).

be always insufficient to reach social optimum. Finally, as there are monopoly distortions, in both cases, nothing ensures market alone will provide an efficient price structure. But the possibility of almost unbounded growth, responding to market and policy incentive, is present.

Let's now describe the characteristics, strengths and limitations of the two models.

3.3.1 Romer's product variety model

The first NGT model was proposed by Romer in 1990 ([284]), as a model where the rate of growth is sustained in the long run by expanding the range of capital inputs used for producing the final output. The great novelty of this model, compared to the previous *AK* models - where productivity growth in the sector producing the final output comes from “*unintentional side effects*” - or to the Solow-type models - where it is assumed exogenous - is that it explicitly represents technical change as the result of the motivation of economic agents for investing in technology. For that, besides the sector producing final output, that is still a competitive sector with pure and perfect competition, Romer introduces two additional sectors: The research sector that invests in human capital and uses the existing stock of general knowledge for producing “(...) *new designs for new producers of durables. An intermediate-goods sectors uses the new designs from research sector together with forgone output to produce the large number of producer durables that are available for use in final good production at any time*” (Romer, *ibid*, P. S79). The model uses simplifying assumptions, such as the supply of the labor force and the population that are constant, but this does not change the conclusions that can be retrieved from the model.

Starting from the sector producing the final good under perfect competition, Romer considers the following production function for the representative firm:

$$Y_t = H_{Yt}^\alpha \cdot L_t^\beta \cdot \sum_{i=1}^A x_{it}^{1-\alpha-\beta}. \quad (3.3.1)$$

where x_i is the durable (or capital good), for variety i , L , the quantity of labor, and H_Y the amount of human capital used for producing the final output. We see that the production function is of Cobb-Douglas type with constant returns to scale, but it differs as the stock of capital, $K_t = \sum_{i=1}^A x_{it}$, is a direct sum of the different quantities of durables used in production. The precursory version of this production function was already proposed in Romer's 1987 paper (Romer, 1987, [282]) published in the American Economic Review, “*Growth Based on Increasing Returns Due to Specialization*”. It

allows Romer, as we will see, to use the monopolistic competition framework introduced by Dixit and Stiglitz (1977, [102]), and later developed by Ethier (1982, [114]). The particularity of this production function is that it is additively separable in x , making the marginal productivity of the various durables independent the ones to the others, while they are implicitly assumed to be perfectly substitutable when using an aggregate capital stock. We will see the advantages of this specification below.

The accumulation of capital can be classically expressed as the accumulation of forgone output and we have:

$$\Delta K_t = Y_t - C_t$$

with C_t , the aggregate final consumption at the date t .

The second sector, the research sector, has for mission to invent new designs that will provide the new capital (or intermediate) goods. It is a competitive sector with free entry and free exit, and the number of new designs that will be produced during each period, ΔN_t , is assumed to be proportional to the aggregate number of individuals (or research labs) that will engage in research, that is to say to the aggregate R&D input, measured in the model by the total amount of human capital that is engaged in research, H_{At} :

$$G(A_{t-1}, H_{At}) = \Delta A_t = \delta \cdot A_{t-1} \cdot H_{At}. \quad (3.3.2)$$

with $\delta > 0$ a positive parameter. We see that research productivity, $\delta \cdot A_{t-1}$, is pushed-up by the total number of new designs that were invented in the past, that acts as a positive inter-temporal externality, reflecting the non non-rivalry and non excludability of the knowledge created. We can already sense at this stage, taking the words of Romer again, that this “*Linearity in A is what makes unbounded growth possible, and in this sense, unbounded growth is more like an assumption than a result of the model*” (Romer, *ibid*, P. S84). Furthermore, the assumption that the innovation process is deterministic is a necessary condition to ensure that new designs will emerge during each period.

Then, once a new variety of durable has been designed, the inventor can rent it out, with an infinite life patent, to the third sector that has the mission to produce all the durables that are used to produce the final output. With this assumption, the durables are produced with forgone output (ΔK_t) and the following production function:

$$x_{it} = \eta \cdot z_t \quad (3.3.3)$$

with x_{it} the quantity of durable i that is produced at period t , z_t , the quantity or forgone output that is necessary for producing x_{it} , and $\eta > 0$, a positive productivity parameter. As the intermediate (or capital goods) sector has a fixed cost that is paid to the research sector for using the new design i , it must charge a price for the durable, to the final good sector, that will ensure that it recovers its fixed cost by applying a positive margin over its marginal cost. Taking the price of the final good as *numéraire*, that is set to 1, the instantaneous profit of the producer of the durable i expresses:

$$\Pi_{Iit} = x_{it} \cdot (P_{it} - \eta) - r \cdot P_{Nit} \quad (3.3.4)$$

with P_{it} , the price of the durable required from the final good sector, and $r \cdot P_{Nit}$ the patent revenues going to the research sector, r , the interest rate, and P_{Nit} the patent market value, that should equate at equilibrium to the actualized sum of all the remuneration the intermediate sector should earn from using the design of variety i .

The price charged to the final good sector should be equal to the marginal revenue it obtains by using the durable i , such as:

$$\frac{\partial \Pi_{Ft}}{\partial x_{it}} = (1 - \alpha - \beta) \cdot H_{Yt}^\alpha \cdot L_t^\beta \cdot x_{it}^{-\alpha-\beta} - P_{it} = 0 \quad (3.3.5)$$

with Π_{Ft} , the profit function of the final good sector (nil at equilibrium), and

$$P_{it} = (1 - \alpha - \beta) \cdot \frac{H_{Yt}^\alpha \cdot L_t^\beta}{x_{it}^{\alpha+\beta}}. \quad (3.3.6)$$

At this stage, we see the interest of the production function used by Romer for the final output, that ensures at the same time that all the varieties of intermediate goods will be used, and that the profit margins owned by the different monopolies in the intermediate sector are independent from each other. We can next plug equation 3.3.6 into equation 3.3.4 :

$$\Pi_{Iit} = x_{it} \cdot \left((1 - \alpha - \beta) \cdot \frac{H_{Yt}^\alpha \cdot L_t^\beta}{x_{it}^{\alpha+\beta}} - \eta \right) - r \cdot P_{Nit} \quad (3.3.7)$$

and find x_{it} that maximizes Π_{Iit} :

$$\frac{\partial \Pi_{Iit}}{\partial x_{it}} = 0 \iff x_{it} = \left[\frac{(1 - \alpha - \beta)^2 \cdot H_{Yt}^\alpha \cdot L_t^\beta}{\eta} \right]^{\frac{1}{\alpha + \beta}}. \quad (3.3.8)$$

As, to simplify, Romer assumes that the total quantities of labor, L , and of human capital, $H = H_Y + H_A$, are fixed, like the total population that is measured by $L + H$, then we see that the quantity of the intermediate of variety i , that is produced, will be constant over time, and its price can finally be re-expressed, using equation 3.3.8 in 3.3.6:

$$P_{it} = \frac{\eta}{1 - \alpha - \beta}. \quad (3.3.9)$$

The value for patent rights, $r \cdot P_{Ait}$, should finally cancel the current profits of the producer of the durable i , as the entrepreneurs in the intermediate sector will bid until the price of the patent equals the inter-temporal rent surplus. This comes after calculations, using equations 3.3.7, 3.3.8, 3.3.9, as the expression for final output (equation 3.3.1), and the fact that at the symmetric equilibrium all the intermediate firms will produce the same amount of output, $x_i = x$, $\forall i$:

$$\frac{P_{Ai} \cdot A_t}{Y_t} = \left[\frac{(\alpha + \beta) \cdot (1 - \alpha - \beta)}{r} \right] \quad (3.3.10)$$

ensuring, that the value of a patent, if Y_t and A_t grow at the same rate (see below) in the long run, is invariant and independent of the date of apparition of the new design i .

Once again using the property that at symmetric equilibrium, all the firms in the intermediate sector will produce the same amount of durables for maximizing their profit ($x_{it} = x$, for all i), then the production function for final output (equation 3.3.1), can be re-expressed:

$$Y_t = F(H_t, L_t, x, A_t) = H_{Yt}^\alpha \cdot L_t^\beta \cdot A_t \cdot x^{1 - \alpha - \beta}. \quad (3.3.11)$$

Also using the fact, according to Romer (ibid, S89), that from equation 3.3.3, $\frac{1}{\eta}$ units of forgone output is necessary to produce 1 unit of durable, it is possible to express x in terms of aggregate capital stock ($x = \frac{K_t}{\eta \cdot A_t}$), then the final output Y_t can be written:

$$Y_t = F(H_t, L_t, K_t, A_t) = (H_{Yt} \cdot A_t)^\alpha \cdot (L_t \cdot A_t)^\beta \cdot K_t^{1 - \alpha - \beta} \cdot \eta^{\alpha + \beta - 1}. \quad (3.3.12)$$

As Romer explains (ibid, P. S89), “(...) the model behaves just like the neoclassical model with labor and

human capital augmenting technological change. It particular, it exhibits the usual diminishing returns to capital accumulation. (...) If A grew at an exogenously specified exponential rate, the economy would converge to a path on which K grows at the same exponential rate than A ". The difference is that the rate of growth of technical change is now endogenous, and comes from the non-convexity introduced in the linear differential equation describing the production of new ideas (equation 3.3.2). It arises from the external effects arising from knowledge externalities (through A) introduced in the research sector, and because the "non-rival" good A is an input in production. Again according to Romer "(...) Both spillovers and price setting seem essential to capturing the features of knowledge in a growth model. There is little doubt that much of the value for society of any given innovation or discovery is not captured by the inventor, and any model that missed these spillovers would miss important elements of the growth process. Yet it is still the case that private, profit-maximizing agents make investments in the creation of new knowledge and that they earn return on these investments by charging a price for the resulting goods that is greater than the marginal cost of producing the good".

The model therefore provides a balanced growth path (BGP) similar to the Solow model, where all the variables: final output, capital stock and final consumption grow at the same rate as technology, g , but with g now endogenous and responding to market incentives and optimization behavior by firms and households:

$$g = \frac{\Delta Y_t}{Y_{t-1}} = \frac{\Delta K_t}{K_{t-1}} = \frac{\Delta C_t}{C_{t-1}} = \frac{\Delta A_t}{A_{t-1}} = \delta \cdot H_{At}. \quad (3.3.13)$$

By using the equilibrium solution for H_{At} ¹⁰ we finally get after several calculations:

$$g = \delta \cdot H_t - \frac{\beta \cdot r}{(\alpha + \beta) \cdot (1 - \alpha - \beta)}, \quad (3.3.14)$$

that provide a decreasing relationship between the growth rate of the economy and the interest rate.

To analyze the growth properties of the model more closely, and its implications in terms of welfare and economic policy, it necessary to close it by solving the optimization problem of households. Romer assumes, like in the first RCK models, that we briefly introduced in section 3.1, that consumers have Ramsey preferences and maximize their inter-temporal utility with a constant discount rate ρ :

¹⁰It is obtained by assuming that at equilibrium engineers (H_Y) and researchers (H_A) will earn the same wage and stop migration from one sector to the other. Then $H_{Yt} = \frac{\beta \cdot Y_t}{\delta \cdot P_{At} \cdot A_{t-1}}$ and, as $H_t = H_{Yt} + H_{At}$, $H_{At} = H_t - \frac{\beta \cdot Y_t}{\delta \cdot P_{At} \cdot A_{t-1}}$.

$$W_{Ht} = \sum_{s=t}^{+\infty} \left(\frac{1}{1+\rho} \right)^{s-t} \cdot U_s(C_s),$$

with W_{Ht} , the welfare function, and with:

$$U_t(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}$$

for $\sigma \in [0, \infty[$, the instantaneous utility function of households. Households are supposed to be “endowed with fixed quantities of labor L and human capital H that are supplied in-elastically”, such as the utility relies only on the quantities of the final good that are supplied. The interesting characteristic of this utility function is that it is isoelastic. The inter-temporal substitution elasticity ($\frac{1}{\sigma}$) between current and future consumption is independent of the initial quantities consumed, and it ensures that the consumer will desire to smooth his consumption over-time. It was introduced by Ramsey (1928), and is known as Keynes-Ramsey rule ensuring the compatibility of the growth rate of consumption with a steady state. As the households’ revenue is formed from revenues they earn from holding capital, here the rent on the durables produced, the optimal consumption smoothing over time verifies that at each period, the marginal rate of substitution between consumption during this period, and the next, would be equate to the marginal rate of earning from holding one additional unit of capital. We then have:

$$\frac{\Delta C_t}{C_{t-1}} = (r - \rho) / \sigma$$

and by using the fact that at equilibrium consumption grows at the same rate as technology $\frac{\Delta C_t}{C_{t-1}} = g$, we obtain:

$$g = (r - \rho) / \sigma \tag{3.3.15}$$

which introduces in the model a positive relation between the rate of growth of the economy and the interest rate.

Combining this last equation with equation 3.3.14, we can then end to solve the model for g and r , algebraically, in terms of the parameter of the model, with for g :

$$g = \frac{\delta \cdot H - \Lambda \cdot \rho}{\sigma \cdot \Lambda + 1} \tag{3.3.16}$$

and for r :

$$r = \frac{\delta \cdot H - A \cdot \rho}{A + 1} + \rho \quad (3.3.17)$$

where $A = \frac{\alpha}{(\alpha + \beta) \cdot (1 - \alpha - \beta)}$.

Our first conclusions on the product variety model of Romer can now be drawn:

- All the original features that Romer introduces in his model, compared to the Solow model, are synthesized in the reduced form equation 3.3.14. Compared to the Solow model, where the growth rate of output, g , is exogenous, this Romer equation makes the growth rate of the economy depend on two variables, the total amount of human capital that is available in the economy, H , that acts positively on the growth rate; and the interest rate, that acts negatively. In the model, growth results from two mechanisms: knowledge externalities arising from the public good nature of general knowledge, that pushes-up research productivity, and the specialization of capital durables that increases productivity in the final good sector. Durables are produced by profit-seeking firms, and any rise in the interest rate will lower the growth rate of the economy, because of their negative impact on the market value of innovations (though the variable P_{Nt}), and on the number of people that will decide to work in the research sector. The model describes a BGP, similar to the one of the Solow model, but that is now endogenous and can be influenced by economic instruments, such as subsidies for research, or tax credits on capital that will increase the rate of accumulation of K , and thereby of A .
- On the consumer side, the Ramsey equation (3.3.15) describes the growth rate of the economy as (1) a positive function of the interest rate, that fosters the investment rate, (2) a decreasing function of the rate of time preference: more impatient consumers leading to less savings and capital accumulation, while, on the other side, (3) a greater value of the inter-temporal elasticity of substitution, $\frac{1}{\sigma}$, makes it easier for consumers smoothing their consumption over time, bringing higher investment in response to a rise in the interest rate, and higher long term growth.
- At the general equilibrium, the equation 3.3.16 shows that the growth rate is still a positive function of human capital stock (H) and of the value of the inter-temporal substitution elasticity, and a negative function of the rate of time preference. It is also a positive function research productivity δ . More surprisingly, in the model, a fall in η , that would increase the returns in the sector that produces the durable, does not increase the growth rate in the economy. This result, as Romer explains (*ibid*, P. S93), comes from a general equilibrium property of the model, that

makes the return on human capital employed in manufacturing increase at the same rate as the return on human capital employed in research, and the two effects cancel each other out. A more controversial effect already described above, is the property that the growth rate of economy, is a positive function of the total stock of human capital, H . It suggests that the biggest countries, with a higher stock of human capital, would grow faster than the others, leading to a divergence in the growth rate of the economies proportional to the size of their population. This scale effect, that is rather counterfactual, as we will see in the section 3.4, would for Romer (*ibid*, P. S98) nevertheless be meaningful to explain the advantages of economic integration: the benefits from the scale effects arising from knowledge spillovers, when integrating with a country with a higher level of human capital.

A last aspect of the model is its implications for welfare by comparing the decentralized equilibrium of the model, described by equation 3.3.16 for the growth rate of the economy, to the growth that would result from the social planning problem. The social planner would still maximize a household's welfare function, W_{Ht} , as above, but taking into account inter-temporal knowledge externalities from research activities, proportional to A , that individual researchers do not internalize. This growth rate (Romer, *ibid*, page S97) is shown by:

$$g = \frac{\delta \cdot H - \Theta \cdot \rho}{\sigma \cdot \Theta + (1 - \Theta)} \quad (3.3.18)$$

where $\Theta = \frac{\alpha}{(\alpha + \beta)}$. Romer shows that the social allocation of human capital to research will be always superior to the decentralized case, causing the social optimum growth rate to be higher. It arises from two effects: (1) the socially optimal reduction of the markup from the monopoly sector and (2) as expected “(...) *the effect of correcting for the external effects associated with the production of new ideas*” (*ibid*, page S98). Romer therefore concludes that “(...) *in the absence of feasible policies that can remove the divergence between social and private returns to research, a second-best policy would be to subsidize the accumulation of total human capital*”.

3.3.2 The “quality ladder” model by Aghion and Howitt (1992) and Grossman and Helpman (1991)

The model of product variety by Romer (1990, [284]) has provided the first general equilibrium model of optimal growth with explicit micro foundations, where the rate of technical change is endogenous, resulting from the inter-temporal profit-seeking behavior of firms and the maximization of utility by

households. Nevertheless the model has several limitations, the principal being that there is no place in the model for firms exit and firms turnover: the new varieties of products introduced on the market by entrant firms, do not displace the old varieties produced by incumbent firms.

In the “*quality ladder*” model proposed by Aghion and Howitt (1992, [4]) and Grossman and Helpman (1991, [152]), on the contrary, innovations by the entrant firms totally delete the monopoly rents owned by incumbent firms. This alternative approach is based on the concept of “*creative destruction*” introduced by Schumpeter, with that idea that innovations incessantly modify and transform the economic structures by which the goods and services are produced, the invention of new products, of better versions of old ones, or of more efficient production processes, making the new products and then new firms replace the outdated ones. Contrary to Romer (1990, [284]), where at each period new firms create their own monopoly without threatening the monopoly rents of incumbent firms, it introduces a true competitive force into the model, by which new firms replace the incumbent ones, and take all the market. Compared to the product variety model of Romer, the mechanisms are as follows:

- The number of intermediate goods that are available no longer increases and endogenous growth does not result, as previously, from the invention, at each period, of new varieties of durable goods, but from the quality improvement in a fixed set of durables. It is not the growth of the number of available intermediate goods that pushes up productivity in the final good sector, but the increasing quality of the fixed set of durables used.
- Research is not a deterministic process, as is Romer (1990, [284]), where this property ensures that at each period new varieties of products will be discovered, but this time it is a stochastic process, with as many research sectors as the number of existing product varieties. This number is nevertheless supposed large enough, for the law of large numbers to apply, which guarantees that at each period a fixed proportion of durables will be improved.
- Exit and firms turnover: the firms that produce the durables with the new quality set a price just below the price of the old quality of the products they replace with their new products. This limit pricing, that was introduced by Grossman and Helpman (1991, [152]), therefore ensures that a new product will take all the market of the old product it replaces. As incumbent firms have no incentive to innovate and to destroy their own monopoly rents, only entrant firms innovate, pushing the incumbent firms out of the market.

- The consequence of this “*business stealing*” effect whereby entrant firms replace incumbent ones with their innovations, is finally important for welfare analysis and its implications for economic policy. In the Romer model, there is only one positive externality: the inter-temporal knowledge spillover that increases research productivity in time, which implies that the market equilibrium will always be associated with a level of investment in research insufficient to reach the social optimum, and justifies the public intervention for supporting research. Here there is, in addition to this positive externality, a negative externality coming from the destruction of the monopoly rents of the incumbent firms by the innovators. This time, the welfare analysis shows that if knowledge externalities are not strong enough, this “*business stealing*” effect can render the private returns to research superior to the public ones, meaning that too much may be invested in research.

We see that the two categories of models complement each other on the type of innovation they represent, horizontal versus vertical; the way they represent the innovation process, deterministic versus stochastic; and finally on the role played by competition and its implication on normative issues. Finally, note that the version of the Schumpeterian model proposed by Grossman and Helpman (1991, [152]) differs from the description above. In this paper, quality improvements concern a fixed set of final goods that enter directly in the utility function of the consumer. It works similarly in their other 1991 publication (Grossman and Helpman, *ibid*, ch. 4), that extends the Romer (1990, [284]) variety model where the utility increases directly as the number of different varieties of final goods that are produced, from the “*love-for-variety*” utility function proposed originally by Dixit and Stiglitz (1997, [102]). In Aghion and Howitt (1992, [4]), on the contrary, innovations enter into the utility of consumers indirectly, from the productivity improvements that are achieved in the final goods sector. The two models have similar analytical and welfare implications, the main difference being that growth is purely qualitative in Grossman and Helpman (1991, [152]), [152], while it is purely quantitative in Aghion and Howitt (1992, [4]).

For simplicity and to alleviate the presentation, we will only present the Schumpeterian model here for this last case, where innovations increase the productivity in the final goods sector. This choice allows us to keep the same presentation as in three sectors above. We continue to use the discrete time notation, and will focus our attention on the main analytical differences between the Aghion and Howitt (1992, [4]) model, and the previous variety model by Romer (1990, [284]).

Starting again with the final goods sector in perfect competition, this time we can express the

production function of the representative firm as follows:

$$Y_t = H_{Y_t}^\alpha \cdot L_t^\beta \cdot \sum_{i=1}^{\bar{N}} A_{it} \cdot x_{it}^{1-\alpha-\beta}. \quad (3.3.19)$$

The main differences from the specification used in the Romer model (equation 3.3.1), are (1) that the total number of existing durable goods, \bar{N} , is now fixed (but supposed large enough), and that (2) at each “*generation*” of intermediate input, x_{it} , is now attached to a specific productivity, or quality level, A_{it} .

In research, there are as many sectors as the total number of durables, \bar{N} . There is still free entry, and in each sector the mission of researchers is to improve the productivity, or quality level, of the latest vintage of intermediate goods. In every sector, a successful innovator increases this productivity (or quality) by a fixed increment, $\gamma > 1$. The research is now considered as a stochastic process, in that, at each period, the probability to innovate follows a Poisson process, of parameter μ_{it} , with:

$$\mu_{it} = \delta \cdot A_{t-1} \cdot H_{A_{it}}. \quad (3.3.20)$$

With the Poisson distribution, the mathematical expectation to innovate equals the law parameter, μ_{it} . We can interpret this parameter as the probability, that at each period, the durable i will have its quality increased by a factor γ . We see that the probability to innovate, is supposed to be an increasing function to the resources that are spent in research, that is to say of the total number of researchers in the sector i : $H_{A_{it}}$. It is also a positive function of the accumulation of general knowledge, A_{t-1} , that acts, similarly to the previous variety model, as a positive inter-temporal knowledge externality pushing up the productivity of research in time. The difference is that A_{t-1} measures this time the “*average*” quality reached by all the durables that are produced, from the direct sum:

$$A_{t-1} = \sum_{i=1}^{\bar{N}} A_{it-1} \quad (3.3.21)$$

Aggregating now over sectors, using the additivity of the Poisson law, and applying the law of large numbers, the proportion of sectors that will innovate at each period is given by:

$$\mu_t = \delta \cdot A_{t-1} \cdot H_{A_t} \quad (3.3.22)$$

with $H_{A_t} = \sum_{i=1}^{\bar{N}} H_{A_{it}}$, the total number of persons working in research at date t . Therefore, at each

period, a fraction μ_t of sectors will innovate, and succeed in inventing the next quality level of their durable i , $A_{it} = \gamma \cdot A_{it-1}$, while the fraction $(1 - \mu_t)$ of sectors that fail to innovate will stay at the quality level A_{it-1} .

At the aggregate level, the average quality of durables that are produced at period t will be therefore:

$$A_t = \mu_t \cdot \gamma \cdot A_{t-1} + (1 - \mu_t) \cdot A_{t-1} \quad (3.3.23)$$

and the average growth rate of durables quality at time t will be:

$$\frac{\Delta A_t}{A_{t-1}} = \mu_t \cdot (\gamma - 1), \quad (3.3.24)$$

which is, as expected, a positive function of the size of the “*quality*” increment and of the average probability to innovate, μ_t .

By combining equations 3.3.22 and 3.3.24, we can express the evolution of the average quality of durables at period t as:

$$G(A_{t-1}, H_{At}) = \Delta A_t = \delta \cdot (\gamma - 1) \cdot A_{t-1} \cdot H_{At} \quad (3.3.25)$$

which is finally totally analog with the research function of Romer’s (1990) variety model (equation 3.3.2), where the increase of the average level of innovation, between two periods, is proportional to a positive parameter (here, $\delta \cdot (\gamma - 1)$), the level of the inter-temporal knowledge externality, A_{t-1} , and the total number persons working in research, H_{At} .

Therefore, while research is a stochastic process at the level of a sector in the quality ladder model, it becomes deterministic at the aggregate level, with a reduced form like in the variety model.

Now turning to the third sector that produces durable goods, when an inventor has discovered a new version of a durable, he/she will protect his/her invention by a patent and rent the rights to produce it to the intermediate sector. If we assume, once again, that one unit of durable i , is produced with η units of forgone output (ΔK_t), then we can show that at equilibrium it will charge the final sector, that uses the durable it produces, exactly the same price as for the variety model (equation 3.3.9):

$$P_{it} = \frac{\eta}{1 - \alpha - \beta}$$

with $\frac{1}{1-\alpha-\beta}$, the mark-up on the marginal cost of production of the durable, η , that allows the intermediate good sector to recover its fixed costs (the patent rights). The important point is that the new product vintage, with the new productivity (or quality) level, is produced exactly at the same cost as the old vintage it replaces. Then, by assuming, as first Grossman and Helpman (1991, [152]) proposed, that the durable producer sets a limit price that falls epsilon to the “unit cost of production of its nearest competitor” (Grossman and Helpman, *ibid*, P. 46) - the monopoly producing the old vintage with a lower quality - then the entrant firm is guaranteed to take the entire market.

This “business stealing effect”, that is not present in the variety model, will necessarily have negative welfare implications, the innovators taking the monopoly rents of the incumbent firm. Therefore, if for all the other aspects, the quality ladder model yields very similar solutions that the variety model, the main difference is that the social optimum will not be necessarily superior to the competitive one. The Schumpeterian feature of the quality ladder model, the creative destruction, implies actually that there may be too much research at the decentralized equilibrium: the growth rate of the economy may be superior or inferior to the optimal one, if the size of innovations (γ), are not big enough to compensate for the destruction of the monopoly rents of incumbent firms by the innovators.

We can finally, as we did previously in the case of the variety model, re-express the final output similarly to that of the Solow neoclassical model of growth, by defining K_t , the aggregate capital stock, as $K_t = \eta \cdot x \cdot \bar{N} \cdot Q_t$, to get:

$$Y_t = F(H_t, L_t, K_t, A_t) = (H_{Y_t} \cdot A_t)^\alpha \cdot (L_t \cdot A_t)^\beta \cdot K_t^{1-\alpha-\beta} \cdot \eta^{\alpha+\beta-1} \quad (3.3.26)$$

which provides exactly the same expression as in the case of the variety model of Romer. The two models therefore have identical reduced forms, provided by the $F(\cdot)$ function for final output, and the $G(\cdot)$ function for the production of innovations. The difference is that the growth rate of innovation provided by the G function, $g = \frac{\Delta A_t}{A_{t-1}}$, is now a measure of the growth of the average quality of the durables that are used in production, and not of the growth rate of the number of product varieties, as in Romer (1990).

Returning on the debate in the previous sections: “Does technological progress cause capital accumulation, or does capital accumulation provoke technological progress ?” (see section 3.1.6), it is clear, using the NGT models, that it is technological progress that creates incentives to invest in the physical equipment, to build the necessary infrastructures for producing new varieties of durables, and/or new

vintages that incorporate improved quality of these durables. Growth, like in the neoclassical model, is equal to the the rate of labor-augmenting technical change, that is now endogenous. But as Aghion and Howitt (2009, [9], P. 118) stressed , “*the conclusions that could be formulated from this last statement must be nuanced (...) because g [the rate of growth of technical change] is now endogenous, so we cannot meaningfully speak of it as causing anything (...) [and, in this general equilibrium setting,] in general the long-run growth rate will be influenced by conditions underlying the research arbitrage equation that governs innovations, but also by the conditions underlying the steady-state capital accumulation*”. For example, policies that stimulate the R&D sector “*will result with higher g , but any policy stimulating the saving rate and investment causes g to go up, and in this case the change is attributable to capital accumulation, since it was a change in shift not a change in innovation that caused the shift*” (Aghion and Howitt, *ibid*, same page). Therefore, the endogenous rate of growth will now be influenced by a wide range of market incentives, and policy interventions.

To conclude this section we must underline, that the quality model suffers from the same “*scale effect*” that was discussed above, in the case of the variety model. In this first generation of NGT models, the rate of growth is proportional to the size of the population (here the human capital), with the immediate implication that bigger countries, with a larger endowment in Human Capital, will experiment a higher rate of growth, leading, as in the case of the *AK* models, to absolute divergence in the growth rate of GDP per *capita* in the different countries. Furthermore, as in most countries the active population is increasing, it should result an acceleration in the growth rate that could even become explosive. As we will see now, these characteristics of this first generation of NGT models were deeply criticized by Jones (1995a, [178], and 1995b, [180]) and by Jones and Williams (1996, [182]) that show the total absence of empirical validation of such results, that led to the adaptations present in the second generation of models, that remove these scale effects.

3.4 The Jones’ criticism of the “*Scale Effect*” and the second generation of NGT models

Jones , in a paper published in 1995 (Jones, 1995a, [178]), “*Time Series Tests of Endogenous Growth Models*”, brought the first and detrimental criticism against the “*scale effect*” present in the first generation of endogenous growth models by Romer (1990, [284]), Grossman and Helpman (1991, [152]) and Aghion and Howitt (1992, [4]) (Thereafter R/GH/AH). Jones’ criticism is centered on the fact

that the two main features of these models, (1) that the long-run growth rate increases with the size of the population, and (2) that it can be influenced by policy incentives. For Jones, both of them are rejected by historical statistics on industrialized and developing countries.

To start with, concerning the “*scale effect*”, Jones observes that in the case of the United States, the rate of growth of GDP per *capita* over a century, from 1880 to 1987, was roughly stable, about 1.8% per year. As the population grew at an exponential rate during the same period, according to R/GH/AH it should have led to the same exponential growth rate of GDP per *capita*, and “*The implication of scale effects is easily rejected by the lack of persistent increase in growth rates (...)*” (Jones, 1995a, *ibid*, p. 516). Jones states for example, that “*(...) the number of scientists and engineers engaged in R&D in the United States has grown from less than 200,000 to almost one million, a more than five-fold increase (...)*”, though no “*distinct*” trend can be observed in the growth rate of *TFP*. For Jones, “*The R&D equation central to the models of Romer/GH/AH, then, violates the time series test (...)*”, and this is valid for other major OECD countries such France, Germany or Japan¹¹¹².

The second part of Jones criticism of the prediction of the R/GH/AH models, that the long term growth rate of GDP per *capita* in industrialized countries could be influenced by economic policy, also relies on an careful analysis of historical statistics. For Jones, “*A hallmark of the endogenous growth literature is that permanent change in variables that are potentially affected by government policy lead to permanent changes in growth rates. This is the result in both the early “AK”-style growth models of Romer [1986, [283]], Lucas [1988, [225]], and Rebelo [1991, [278]], as well as in subsequent models focusing more explicitly on endogenous technological change by Romer [1990, [284]], Grossman and Helpman [1991, [152]] and Aghion and Howitt [1992, [4]]. This “growth effect” result stands in marked contrast to the neoclassical growth model proposed by Solow [1956, [300]], in which the presence of long-run growth depend crucially on exogenous technical change*” (Jones, 1995a, *ibid*, page 495). There therefore are for Jones in this literature, following the Grossman and Helpman literature review (1991a, [152], 1991b, [151]), “*(...) no fewer than ten potential determinants of long-run growth, including physical investment rates, human capital investment rates, export shares, inward orientation, the strength of property rights, government consumption, population growth, and regulatory pressure. Permanent changes in these variables, at least according to some endogenous growth models, should*

¹¹The sample of additional countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden and the United Kingdom.

¹²Jones limits the sample to industrialized countries as “*(...) the process of industrialization and development is likely to be different from the process of generating the sustained growth of the countries that have already industrialized*” (Jones, 1995a, *ibid*, Page 501).

lead to permanent change in growth rates” (Jones, 1995a, *ibid*, page 495). Jones shows that over the past 40 years in OECD countries, many of these variables encountered “(...) large, persistent movements, generally in the growth increasing direction” (Jones, 1995a, *ibid*, page 496). No similar persistent increase in the growth rate of GDP per *capita* in OECD countries can be observed over 40 years since the World War II, and “(...) what change has occurred has been down rather than up” (Jones, 1995a, *ibid*, same page). This contradicts the prediction of the endogenous growth theory, and, for Jones, “Two possibilities are suggested: either by some astonishing coincidence all the movements in variables that can have permanent effects on growth rates have been offsetting, or the hallmark of the endogenous growth models, that permanent changes in policy variables have permanent effects on growth rates, is misleading” (Jones, 1995a, *ibid*).

This criticism of Jones of the first generation of endogenous growth models was very influential, and led to the development of a second generation of models, extending the first generation, in such a way that it removes the scale effect. Two streams of literature developed, almost in parallel:

The first, introduced by Jones in a second 1995 paper (Jones, 1995b, [180]), extends the initial product variety model of Romer (1990, [284]) to form a first class of “*second generation models*” that was labeled “*semi-endogenous*” by Jones (1995b, *ibid*). In the model, the consequence of removing the scale effect leads to the property that it becomes policy invariant in the long-run. The long-run steady states therefore relies on the growth rate of population alone, similarly to the “old” neoclassical model introduced by Solow; but with the difference that long-run growth still occurs from innovations made by profit-seeking firms and individuals, just like in the first generation of NGT models. There no longer exists what Jones (1999, [179]) calls a “*strong scale effect*” leading to exploding growth rates, like in the first generation models where the growth rate is proportional to the size of population, but there is now a “*weak scale effect*”, with a long-run growth rate that is this time proportional to the growth of population. For Jones, this last feature of the model is supported by the time series evidence he reported in his first 1995 paper, as it is ultimately the growth of the total number of persons engaged in the R&D sector that will support the growth rate of innovations in the future. This policy invariant result of the semi-endogenous models introduced by Jones became quickly controversial, and a second stream of the literature developed, where this time the removal of the “*scale effect*” does not lead to the conclusion that the long-run rate of growth is policy invariant.

This second class of “*second generation models*” was based on an extension of the quality ladder models by Grossman and Helpman (1991, [152]) and Aghion and Howitt (1992, [4]), with the common

idea to permit a rise in the total number of available product varieties in the model. If for example, following Young (1998, [335]), the number of products increases exogenously as the scale effect (the size of population), the amount of research that can be spent for increasing the quality of each variety of products cannot be increased, and this “*dilution effect*” of the research effort between an increasing range of products suppresses the scale effect. In these models, developed by Young (1998, [335]), Aghion and Howitt (1998, [8], chapter 2), Dinopoulos and Thomson (1998, [101]) and Howitt (1999 [165]) (Thereafter the Y/P/AH/DT/H models), the long-run growth rate of GDP per *capita* now depends on the investment rate in research, that is a variable that can be influenced by policy instruments, preserving the “*fully endogenous*” characteristics on the first generation of endogenous growth models.

The two next sections analytically detail the main features of these two classes of “*second generation*” models, then, building on Li (2000, [216]) and Jones (1999, [179]), a last section shows how the two approaches can be combined within a two-R&D sector model.

3.4.1 Jones’ semi-endogenous approach

Jones’ criticism of the first generation of models, is based on his statement that they do not conform to the time-series evidence for industrialized countries over the past decades. For Jones, the central implications of these models, that the long-run growth rate of per capita GDP depends on a scale effect proportional to the size of the population, and that it could be influenced by economic instruments. Both result on theoretically unrealistic choices for the parameter values that are retained in them.

We have seen in the preceding sections that the two models share the same $F(\cdot)$ and $G(\cdot)$ functions reduced form, that we can write to simplify, following Jones (1995b, [180]), as:

$$Y_t = F(L_{Yt}, K_t, A_t) = A_t L_{Yt}^{\alpha} \cdot K_t^{1-\alpha} \quad (3.4.1)$$

and:

$$\Delta A_t = G(A_{t-1}, L_{At}) = \delta \cdot A_{t-1} \cdot L_{At} \quad (3.4.2)$$

where there is this time only one category of labor, that can be used alternatively to produce final output (L_{Yt}) or for the invention of new ideas (L_{At}), new ideas (ΔA_t) representing either horizontal or vertical innovations.

As Jones explains, the source of the scale effect resides in the equation $G(\cdot)$ for innovation, that implies that the growth rate of innovations and *TFP*, $\frac{\Delta A_t}{A_{t-1}}$, will be proportional to the total number of

persons that have joined the R&D sector. Therefore, if the population grows at a constant exogenous rate, n , and the share of labor employed in the R&D sector is constant in the long-run, the growth rate of GDP per capita in this economy will increase by a factor $1 + n$ each year, leading to explosive growth rates.

To remove this scale effect, Jones first proposes to rewrite the production function for new ideas, as:

$$\Delta A_t = \bar{\delta} \cdot L_{At}. \quad (3.4.3)$$

With this equation, if A_t designates the stock of knowledge of an economy, it is simply an accumulation of new ideas, ΔA_t , that are developed by people, L_{At} . The number of new ideas is itself proportional to the number of persons working in the R&D sector, times the rate of arrival of new ideas, $\bar{\delta}$, as in the Poisson specification in the micro-foundation of the quality ladder models of Grossman-Helpman (1991, [152]) and Aghion-Howitt (1992, [4]).

Now, like in the Romer/GH/AH first generation of models and the equation 3.4.3 above, we could expect that the rate at which researchers discover new ideas is influenced by past discoveries, from the “*standing-on-shoulder*” effect resulting from the non-rivalry of general knowledge, therefore proposes to parameterize the arrival rate in function of A , such as:

$$\bar{\delta} = \delta \cdot A_{t-1}^\phi. \quad (3.4.4)$$

Jones (1995b, *ibid*) explains page 765 of his article that “*In this equation, $\phi < 1$, corresponds to the case referred in the productivity literature as the ‘fishing out’, in which the rate of innovation decreases with the level of knowledge; $\phi > 1$ corresponds to the positive external returns case. A value $\phi = 0$ represents the useful benchmark of constant returns to scale (from external returns) in which the arrival rate of new ideas is independent of the stock of knowledge*”. All these effects of course remain external to the individual agents and “*(...) occur across time in the R&D process*”, as in the former R/GH/AH models.

Jones finally introduces the possibility, he calls the “*stepping on toes effect*”, that, at a given period, “*(...) the duplication and overlap of research reduce the total number of innovations produced by one L_A units of labor*” (Jones, 1995b, *ibid*, same page). It is for example implicit in the quality ladder model of Grossman-Helpman (1991, [152]) and Aghion-Howitt (1992, [4]), where in each sector individuals or

firms search to improve the quality of the same product variety. Then it is L_A^λ , $0 < \lambda \leq 1$, and not L_A , that intervenes in the R&D equation, introducing these two last changes in equation 3.4.3 that finally yields:

$$\Delta A_t = \delta \cdot A_{t-1}^\phi \cdot L_{At}^\lambda. \quad (3.4.5)$$

We see that taking the case $\phi = 1$ and $\lambda = 1$ sends us back to the R&D function as described by the R/GH/AH models. While the choice retained for the value of the parameter λ does not have consequences on the “*fully endogenous*” or “*semi-endogenous*” nature of the long-run growth rate in the model, the choice of $\phi = 1$ in the Romer/GH/AH models is for Jones completely arbitrary and is inconsistent with the historical data for industrialized countries, as argued above. It represents an arbitrary “*knife-edge*” assumption, like in the *AK*-style models, where the positive externalities from capital accumulation are supposed to compensate for the marginal decreasing returns to capital at the individual level exactly .

As the case $\phi > 1$ would lead to explosive growth rates even for values for ϕ just above 1, Jones therefore focuses his attention on the last case, where $\phi < 1$ and the “*fishing-out*” effect predominates. The expression of the steady-state growth rate of TFP and GDP per capita in this case can be obtained easily by reformulating equation 3.4.5 above in terms of the growth rate of innovations:

$$\frac{\Delta A_t}{A_{t-1}} = \delta \cdot \frac{L_{At}^\lambda}{A_{t-1}^{1-\phi}}. \quad (3.4.6)$$

If the growth rate of innovation is by definition constant in the long-run, the numerator and the denominator at the right and side of equation 3.4.6 above must grow at the same rate, which implies:

$$\frac{\Delta A_t}{A_{t-1}} = \frac{\lambda \cdot n}{1 - \phi}. \quad (3.4.7)$$

Developing the model fully with this parameter setting for the case of the product variety models of Romer¹³ (1990, [284]), Jones shows that all the “*interesting growth rates in the model*” are pinned down by this growth rate to form a balanced growth path, such as:

¹³In the variety and the quality models sharing the same reduced form, Jones could as well introduce his semi-endogenous growth mechanisms in this latter, as Kortum (1997, [198]) and Segerstrom (1988, [295]) did later.

$$g_A = g_y = g_c = g_k = g = \frac{\lambda \cdot n}{1 - \phi} \quad (3.4.8)$$

where g_y , g_c and g_k designate the growth rate per capita, of respectively, final output, final consumption and investment. To again cite Jones, “Equation (8) [3.4.8] states that the growth rate of the economy in the steady state depends only on the labor force and the parameters ϕ and λ , which determine the external returns (as well as the returns to scale) in the R&D sector” (Jones, 1995b, *ibid*, page 767).

Jones underlines that assuming $\phi = 1$, as in the R/GH/AH models, no balanced growth path could exist, as the growth of population would lead to explosive growth rates, and that assuming $\phi < 1$ is enough to eliminate this “devastating scale effect”, that is replaced by “(...) an intuitive dependence on the growth rate of the labor force rather than on its level” (Jones, 1995b, *ibid*, page 768).

But by removing the scale effect in this way, the consequence that is obvious from equation 3.4.8 is that in the “Steady state growth is invariant to government tax policy, including credits and R&D subsidies” (Jones, 1995b, *ibid*, page 769).

To better investigate this policy-invariance of the long run-growth rate to economic policy, Jones then analyses how the transition dynamics of the model evolve by exogenously increasing the R&D input from one percent, the benchmark case, to two percent of the labor force. The main focus of the simulation exercise is on the length of the transition dynamics of the model, when increasing the R&D input for different values of ϕ and λ . Jones shows that the half-life duration of the transition of “TFP” ($\frac{\Delta A_t}{A_{t-1}}$) is very long and that it is again longer for “labor productivity” (output per *capita*). For $\phi = 0$ (no spillovers case), the half-life is 35 years for TFP and 62 years for labor productivity. When ϕ rises, the half-life rise considerably and becomes infinite when ϕ approaches 1. It is respectively 69 and 120 years for $\phi = 0.5$, 139 and 242 years for $\phi = 0.75$, and 347 and 674 years for $\phi = 0.90$.

The parameter governing the R&D productivity, λ , has itself little impact on the length of the transition dynamics, but governs the magnitude of the effects that result from increasing R&D input, especially in the short term. As it is evident from equation 3.4.8, there therefore exists a trade-off between ϕ and λ , large values of ϕ (approaching 1) requiring small values for λ , to get realistic elasticities of GDP per *capita* to the R&D input, when confronting, for example, the simulation results with those of the econometric literature on R&D and productivity.

The length of the transition dynamics in this semi-endogenous growth model therefore leads to putting the policy invariance property of the model in the long-run into perspective. Nevertheless, this

conclusion from the semi-endogenous growth model was soon controversial, and the debate between the partisans of the semi-endogenous approach, and of the fully endogenous one, that we will present now, is still open.

3.4.2 The second generation of “fully endogenous” models

In parallel to the semi-endogenous growth models, a second stream of the literature developed (Y/P/AH/DT/H models), that tried to get ride of the scale effect, but without suppressing the possibility for economic policy to influence the long term growth rate. The common idea of these models, following Young (1998, [335]), was to allow the number of product varieties to increase in the original quality ladder models of Grossman and Helpman (1991, [152]) and Aghion and Howitt (1992, [4]). The production function can still be represented by equation 3.4.1 above:

$$Y_t = F(L_{Yt}, K_t, A_t) = (L_{Yt} \cdot A_t)^\alpha \cdot K_t^{1-\alpha} \quad (3.4.9)$$

with that difference that the aggregated stock of ideas, A_t , now expresses:

$$A_t = N_t \cdot Q_t. \quad (3.4.10)$$

where N_t , is the number of different product varieties, that was fixed in the original quality ladder model of Grossman and Helpman (1991, *idib*) and Aghion and Howitt (1992, *ibid*) ($N_t = \bar{N}$), but is now allowed to increase, and where Q_t denotes the average quality of products.

Lets suppose, first, that the number of product varieties increases proportionally to the size of total population, L_t . This can be the case, for example, if horizontal innovations can be obtained by simple imitation, without investing in research, by assuming, for example, that as the population grows and the technology of old products banalizes, it becomes easier and easier to invent new varieties of products. We therefore have $N_t = L_t$.

At the aggregate level, the direct consequence of this “*product proliferation*” with population growth, is that more and more research is necessary to increase the average quality of products. As the same amount of research as previously is needed for improving the quality of a product by a factor γ in a given sector, the increase in the number of products causes a dilution effect of the research investments over a growing number of sectors. This can be shown, at the equilibrium, by the following law of evolution of the aggregate quality of products in the economy:

$$\Delta Q_t = G(Q_{t-1}, L_{Qt}) = \delta_Q \cdot \frac{Q_{t-1}}{N_t} \cdot L_{At} \quad (3.4.11)$$

where ΔQ_t , δ_Q , Q_{t-1} , and L_{At} , are, respectively, the variation of product quality, a positive parameter, the inter-temporal general knowledge externality and total investment in research. The novelty is the presence of the variable N_t , at the denominator, that acts as a negative externality, decreasing the average productivity of research as N_t increases and the number of sectors in the economy proliferates.

From equation 3.4.11, and by retaining the assumption that $N_t = L_t$, the average growth of products quality, g_Q , is now

$$g_Q = \frac{\Delta Q_t}{Q_{t-1}} = \delta_Q \cdot \frac{L_{At}}{L_t}, \quad (3.4.12)$$

and we see that the growth rate of average product quality, in the model, is proportional to the investment rate in research, measured here by the proportion of the total labor force that is working in research: $\frac{L_{At}}{L_t}$.

Now, to express the growth rate of output per capita along a balanced growth path (g_y), it results immediately from equations 3.4.9 and 3.4.10 above as:

$$g_y = g_N + g_Q. \quad (3.4.13)$$

As the number of products grows at the same exogenous rate as the population, $g_N = n$, and as at equilibrium the number of persons that work in research, L_{At} increases proportionally to the size of population, L_t , we have in the long-run, $g_Q = \delta_Q \cdot \frac{L_{At}}{L_t}$, and finally:

$$g_y = n + \delta_Q \cdot \frac{L_{At}}{L_t}. \quad (3.4.14)$$

Therefore, when the number of sectors increases with the population, the long-run growth rate of output per *capita*, is no longer dependent on the scale effect of the first generation of models. As Jones (1999, [179]) explains, in Young's (1998, [335]) model, "(...) *any increase in the reward to innovation resulting from a larger population will be dissipated in the long run by the product proliferation it induces: the larger economy will have to allocate a larger number of workers on the innovation process in order to maintain a constant rate of productivity growth because those workers must improve a larger*

number of products” (Jones, 1999, [?], page 716).

Another appealing feature of the model, compared to the semi-endogenous model proposed by Jones (1995b, [180]), Kortum (1997, [198]) and Segerstrom (1988, [295]) (J/K/S, thereafter), is that it removes the scale effect without removing the dependence of the long-run growth rate to economic policy: this later relies on the investment rate in research that can be influenced by usual instruments such as R&D subsidies and tax-credits.

Finally, with this model, the equilibrium growth rate of the economy has two independent components: (1) an exogenous one proportional to the growth of population - as in the semi-endogenous models introduced by Jones -, that increases innovation on the horizontal line; (2) an endogenous one, that relies on the rate of investment in research on the vertical line. It therefore generalizes the semi-endogenous growth model introduced by Jones, by adding a growth component that can be influenced by permanent policy changes, even in the long-run, to the growth rate of population.

We must underline that in the more general setting of the Y/P/AH/DT/H models, horizontal innovation does not occur exogenously, as we have assumed above; it depends, like vertical innovation, on investment in research. But these models introduce an important asymmetry between the two types of innovation: There is still an inter-temporal knowledge externality along the vertical line, that makes future research easier from the accumulation of past ideas; but not along the horizontal line. It is this absence of increasing returns along the horizontal line, that prevents the long-run scale effect in the model. Therefore, along the horizontal line, an increasing amount of resources must be invested for sustaining the growth rate of product varieties, while, along the vertical line, the increasing number of products has a dilution effect, reducing the aggregate returns of research.

For illustration, lets now consider, like in Dinopoulos and Thomson (1998, [101]) that extend the model of Young, that the investment in research is distributed between the two categories of innovation, so as we have $L_{Qt} = S_Q \cdot L_{At}$, with L_{At} , as previously, the total quantity of labor that is employed in research, S_Q , the share of researchers that are developing vertical innovation, and, $L_{Qt} = S_Q \cdot L_{At}$ and $L_{Nt} = (1 - S_Q) \cdot L_{At}$, respectively, the total number of researchers working either on improving products quality, or on increasing the number of existing product varieties.

The increase in the number of product varieties is therefore specified in the models typically as:

$$\Delta N_t = G(L_{Nt}) = \delta_N \cdot L_{Nt} \tag{3.4.15}$$

with δ_N a positive parameter, L_{Nt} the number of persons working to invent new product varieties,

and where the inter-temporal knowledge externality of the initial variety model by Romer has been removed.

Now, on the vertical line, we can, from, equation 3.4.11, express the average growth of product quality along a balanced growth path, g_Q , as

$$\frac{\Delta Q_t}{Q_{t-1}} = \delta_Q \cdot \frac{L_{Qt}}{N_{t-1}}, \quad (3.4.16)$$

This expression is finally very close to equation 3.4.12 above. The main difference is that the growth rate of the average quality of products depends on the share of researchers working on the vertical line, and not on the total resources that the economy invests in research, L_{At} . Consequently a trade-off now exists, in the model, between the amounts that are invested in the two lines of research, that will influence the expression of the equilibrium growth rate of GDP per capita.

To analyze the implications of this trade-off on the expression of the equilibrium growth rate of the economy, lets consider that along a balanced growth path, the share of the labor force working in research, S_A , and the share of researchers working on the vertical line, S_Q , are both constant. As along the balanced growth path, the growth rate of GDP per *capita*, g_y , equals the growth rate of innovation, $g_A = g_N + g_Q$, we have, from equations 3.4.15 and 3.4.16:

$$g_y = g_N + g_Q = \frac{\Delta N_t}{N_{t-1}} + \frac{\Delta Q_t}{Q_{t-1}} = \delta_N \cdot \frac{L_{Nt}}{N_{t-1}} + \delta_Q \cdot \frac{L_{Qt}}{N_{t-1}}$$

which leads after re-arrangement, using the fact (from equations 3.4.15 and 3.4.16) that N should grow at the same rate as the population in the long run ($g_N = n$) to:

$$g_y = \left(1 + \frac{\delta_Q}{\delta_N} \cdot \frac{S_Q}{1 - S_Q} \right) \cdot n. \quad (3.4.17)$$

Therefore, as previously in the Young 's (1998, [335]) model, the long-run growth rate of GDP per *capita* is no longer dependent on the size of population, and is not explosive. The “strong scale effect” has been removed, but there is still a “weak scale effect” in the model, as the long-run growth rate is proportional the growth rate of the population, just like in the J/K/S semi-endogenous growth models. Anyway, this long-run growth is not policy invariant, and any policy increasing the share of quality R&D (S_Q), will increase g_y . It is therefore still fully endogenous, like in the first generation of models. But we see, that a generic policy, increasing variety and quality innovations proportionally, will not have an impact on the long-run rate of growth, because of the “*dilution effect*” that is associated with

the increase of the number of product varieties.

On the contrary, other variants of models were developed, where the effectiveness of a general subsidy for R&D is preserved, like in Aghion and Howitt (1998, [8], chapter 2) and Howitt (1999, [165]). But the common feature of all these models remains that the suppression of the scale effect results from the asymmetry that is introduced into the model, between vertical and horizontal innovation¹⁴. The returns are constant along the vertical line, but decreasing along the horizontal one. Therefore, for Jones (1999, [179]), these models still rely on knife-edge conditions for parameter values, exactly like the first generation of models. And, for Jones (1999, [179]), as for Li (2000, [216]), a more general model, with two innovation lines, remains semi-endogenous.

3.5 Semi-endogenous growth, fully-endogenous growth, or both?

Jones recognizes in his 1999 paper ([179]), that introducing a second line of research for removing the scale effect, in the Y/P/AH/DT/H models, is important for at least two reasons: (1) it reinstates the result of the first generation models that long-run growth can be influenced by policy, and (2) it removes the limitation of the J/K/S' one sector semi-endogenous growth models, that long-run exponential growth cannot be sustained in the absence of population growth. He shows that the three classes of models can be encompassed in a simple unified framework, providing complementary views on the way economic growth takes place. Li (2000, [216]) generalizes this framework by opening up the possibility of spillovers between the two R&D activities, with the consequence that semi-endogenous growth emerges as a general case, whereas fully-endogenous growth becomes a special case. Finally, the debate on endogenous versus semi-endogenous growth turned towards empirical validation, showing that each approach reflects part of the “true” growth process. The rest of this section will demonstrate these three points, by when necessary adapting the original frameworks that are used in the different papers that we will review.

Starting with Jones' 1999 paper, let's consider the following two sector R&D model adapted from Young (1998, [335]), with:

$$Y_t = F(L_{Yt}, K_t, A_t) = (L_{Yt} \cdot A_t)^\alpha \cdot K_t^{1-\alpha} \quad (3.5.1)$$

¹⁴There exists few exceptions, such as in Peretto (1998, [266]) that only considers variety innovations,

$$A_t = N_t \cdot Q_t. \quad (3.5.2)$$

$$\Delta Q_t = G(Q_{t-1}, L_{Qt}) = \delta_Q \cdot \frac{Q_{t-1}^\phi}{N_t} \cdot S_A \cdot L_t \quad (3.5.3)$$

with $S_A = L_t - L_{Yt}$, the share of the labor force that is used in research and

$$N_t = hL_t^\beta. \quad (3.5.4)$$

The main differences with the specification of the model of Young, presented in the preceding section, is that Jones, as in his 1995 paper, opens the way for fishing-out, in equation 3.5.3, from the parameter ϕ , and for the possibility - similarly to his “*stepping on toes effect*” - that the number of new product varieties grows at a different rate than population, with the introduction of the parameter β in equation 3.5.4.

The growth rate of output per capita becomes, in this extended framework

$$g_y = g_N + g_Q = \beta \cdot n + \delta_Q \cdot \frac{S_A \cdot L_t^{1-\beta}}{Q_{t-1}^{1-\phi}}. \quad (3.5.5)$$

We see, as Jones comments page 143 of his article, that “*This general model embeds each of the three classes models (I have discussed in this paper) [that appear] as special cases and also allows for more general cases. One can show that, asymptotically, growth either explodes, or is characterized by one of the three special cases, depending on the values taken by β and ϕ* ”.

If $\beta \approx 0$ and $\phi \approx 1$, growth is characterized by the R/GH/AH class of models, and $g_y = \delta_Q \cdot S_A \cdot L_t$.

If $\beta < 1$ and $\phi < 1$, growth is described by the J/K/S class of models, and $g_y = \frac{1-\phi \cdot \beta}{1-\phi} \cdot n$.

If $\beta \approx 1$ and $\phi \approx 1$, the growth is characterized by the Y/P/AH/DT/H class of models, and $g_y = n + \delta_Q \cdot S_A$.

Therefore, for Jones (1999, *ibid*, again page 143), “*Without empirical work designed to estimate the parameters values, it is impossible to say which class of models provides the best characterization of long term economic growth*”. But looking at the parameters restrictions that each class of models imposes, it appears that the semi-endogenous family that could embrace the larger range of parameters values, as the two other families need two strict knife-edge restrictions to occur.

Li, in his 2000 paper (Li, 2000, [216]), goes one step further in imposing the generality of the

semi-endogenous growth models. For Li, as we reviewed in the preceding section, the “*striking*” result established by the one-R&D sector models, that growth is independent of public policy in the long-run, was challenged in several studies introducing “*sophisticated two-R&D-sector models*”. “*Their central message is that the semi-endogenous growth is limited to one-R&D sector models, and its associated policy implications have little relevance to a real world in which there are diverse types of research activities*” (Li, 2000, *ibid*, page C109). But, as Jones(1999, *ibid*) opened the way, these latter two-R&D-sector models can also be challenged by even more sophisticated two-R&D-sector models. Therefore, for Li, “*Typically, these studies assume no, or very limited knowledge spillovers between quality and variety R&D, and it is this assumption that drives their result*”. Or, for Li, “*(...) there is no reason, why there should be little inter-R&D spillovers*” (Li, 2000, *ibid*, page C110). The empirical literature on R&D and productivity finds, on the contrary, strong spillovers across industries, and in some studies “*(...) about three times as large as that to R&D within an industry. Moreover, knowledge spillovers between two different types of research activities, scientific and technological, are widely recognized (...) and the pattern of modern knowledge accumulation is increasingly inter-disciplinary, e.g. the transistor is the product of physics, chemistry and metallurgy. (...) [and by allowing for such inter-R&D externalities the] two-R&D sector models no longer generally produce endogenous growth, and instead semi-endogenous growth becomes the norm*” (Li, 2000, *ibid*, same page, continue).

To demonstrate these results, Li begins with an adapted version of the Grossman and Helpman model (1991, Ch. 3 and 4, [151]), with quality and variety innovations, positive population growth, and three sectors: final goods, intermediate goods and R&D. The novelty of the model is that there are now externalities within vertical and horizontal innovations, like in Jones (1999, [179]), but also between horizontal and vertical innovations. At the aggregate level, the reduced form of the model generalizes the two-R&D sector model we studied in the preceding section, where the equations 3.4.15, for variety innovations, and 3.4.16, for quality innovations, are replaced respectively by the two following equations:

$$N_t = \delta_N \cdot N_{t-1}^{\phi_N} \cdot \frac{Q_{t-1}^{\delta_N} \cdot L_{Nt}}{Q_{t-1}}, \quad (3.5.6)$$

and

$$Q_t = \delta_Q \cdot N_{t-1}^{\phi_Q} \cdot \frac{Q_{t-1}^{\delta_Q} \cdot L_{Qt}}{N_{t-1}}, \quad (3.5.7)$$

In these equations, the parameters $\phi_N > 0$ and $\delta_Q > 0$ reflect, as usual, the strength of the intra-R&D knowledge externalities, with the novelty that there are now externalities along the horizontal line. But the main change, is as announced, the presence of the terms $Q_{t-1}^{\delta_N}$ and $N_{t-1}^{\phi_Q}$, with $\delta_N > 0$ and $\phi_Q > 0$, that introduce positive inter-R&D spillovers into the equations. The model is now perfectly symmetric, the term N_{t-1} at the denominator, in equation 3.5.7, as usual reflects the negative impact of the proliferation of the number of product varieties on the productivity of quality R&D, while the term Q_{t-1} , similarly introduces an increasing difficulty in inventing new varieties of products, as their average degree of “*sophistication*” increases.

As in a steady state, the nominator and the denominator should grow at the same rate in equations 3.4.15 and 3.4.16, so we have

$$(1 - \phi_N) \cdot g_N + (1 - \delta_N) \cdot g_Q = n \quad (3.5.8)$$

and

$$(1 - \phi_Q) \cdot g_N + (1 - \delta_Q) \cdot g_Q = n. \quad (3.5.9)$$

We also have, from equations 3.5.1 and 3.5.2, $g_y = g_N + g_Q$, so we can finally solve the system for g_y by using this last relation and the equations 3.5.8 to 3.5.9 above. Then again, different cases emerge depending on the parameters values.

In the general case where $\phi_N \neq \phi_Q$ and $\delta_N \neq \delta_Q$, the equations 3.5.8 and 3.5.9 above are linearly independent. Both growth rates of g_N and g_Q are pinned down by the growth rate of population. It is the semi-endogenous case that generalizes the J/K/S models. We now have

$$g_y = \frac{\phi_N - \phi_Q + \delta_N - \delta_Q}{D} \cdot n$$

with $D = (1 - \phi_Q)(1 - \delta_N)(-1 - \phi_N) \cdot (1 - \delta_Q) \neq 0$. So an interior solution, $g_N, g_Q > 0$, may exist, with two symmetric cases. In the first, for the two R&D, the knowledge created by its own R&D must be more important than the knowledge created from outside R&D ($\phi_N > \phi_Q$ and $\delta_N < \delta_Q$), and conversely in the other case ($\phi_N < \phi_Q$ and $\delta_N > \delta_Q$). Corner solutions bring us back the one-R&D sector semi-endogenous growth models. With $\phi_N, \phi_Q < 1$, and $\delta_N, \delta_Q > 0$, if $\phi_N \leq \phi_Q$ and $\delta_N < \delta_Q$, long-run growth is driven only by variety innovation like in Jones (1995b, [180]), and it is alternatively

driven only by quality innovation when $\phi_N > \phi_Q$ and $\delta_N \geq \delta_Q$, like in Kortum (1997, [198]) and Segerstrom (1998, [295]).

The fully endogenous class of models of the second generation (Y/P/AH/DT/H), requires two knife-edge conditions. These are $\phi_N = \phi_Q = 0$ and $\delta_N = \delta_Q = 1$ that send us back to the case where there is no fishing-out, no intra-sectorial knowledge externalities along the horizontal line, and no inter-R&D knowledge externalities. Once again we have, like in the previous section, $g_y = \left(1 + \frac{\delta_Q}{\delta_N} \cdot \frac{S_Q}{1-S_Q}\right) \cdot n$. A subsidy to R&D increasing the share of quality R&D, would allow the long-run growth rate of output per capita to increase. But in this more generic frame, other classes of endogenous growth models can be obtained. First we can take the symmetric case of the Y/P/AH/DT/H models, by setting $\phi = \phi_Q = 1$, and $\delta_N = \delta_Q = 0$, which provides $g_y = \left(1 + \frac{\delta_N}{\delta_Q} \cdot \frac{1-S_Q}{S_Q}\right) \cdot n$. This time, there are no knowledge externalities along the vertical line, and the R&D policy should consist in increasing the share of variety R&D, in order to stimulate the long-run growth rate. Even more general endogenous growth cases can be also derived, that generalize the two latter, by setting $\phi = \phi_N = \phi_Q$ and $\delta = \delta_N = \delta_Q$. This implies identical knowledge structure in the two R&D activities. In this case, a subsidy for variety R&D will increase the long-run growth rate if $\phi > \delta$, and it will be the opposite if $\phi < \delta$. In both situations, a generic R&D subsidy will have no long-run impact.

Finally, the model encompasses the first generation of endogenous growth models, by setting for example $\phi_N = \phi_Q = \delta_N = \delta_Q = 1$. In this case, the strong scale effect of the Romer/GH/AH models is present, and we have variety and quality innovations at the same time.

Then Li asks, “*Is R&D-driven growth endogenous or semi-endogenous?*” (Li, 2000, *ibid*, page C119). For Li, introducing inter-R&D knowledge spillovers in a two-R&D sector model demonstrates the generality of the semi-endogenous growth models, as fully endogenous growth requires “*(...) two knife-edge conditions in contrast to only one such condition in one-R&D sector model*” (Li, *ibid*, same page). Li generalizes this finding by establishing that “*(...) if there are k R&D sectors where $k > 2$, endogenous growth requires k knife-edge conditions in the presence of inter-R&D spillovers*”. Increasing the diversity of R&D makes endogenous growth less likely to occur, and further strengthens the generality of the semi-endogenous growth result “*(...) [and] Ultimately, the knife-edge conditions should be tested empirically*” (Li, *ibid*, pages C112 and C119).

Now for the last point, the empirical support for the semi-endogenous and the second generation of endogenous growth models, following the invitation of Li and Jones to test the “*knife-edge conditions*”, with new literature developed from the beginning of the 2000s. The common idea of these studies

is to use, as in the Jones (1999, [179]) and Li (2000, [216]) papers, an encompassing framework that econometrically tests the robustness of the parameter restrictions imposed by the different models at the aggregate level. Starting again from the functions $F(\cdot)$ (for final output: Y_t) and $G(\cdot)$ (for the creation of new ideas: ΔA_t), that sum-up the reduced forms of the different models, Ha and Howitt (2007, [153]) propose, for example, to use a G function similar to

$$\Delta A_t = \delta_R \cdot \left(\frac{L_{At}}{Z_t^\sigma} \right)^\beta \cdot A_{t-1}^\phi, \quad (3.5.10)$$

for the protocol of test where δ_R is a positive parameter influencing the productivity of research, L_{At} is the R&D input, that we continue to measure, to simplify, as the labor force that works in the R&D sector, such as $R_t = S_A \cdot L_t$, and with Z_t an index of product proliferation that can be proxied empirically, by any variable that grows in the long-run at the same rate as population, L_t .

For the function F , it admits the same generic form as for the different endogenous growth models we have surveyed

$$Y_t = (L_{Yt} \cdot A_t)^\alpha \cdot K_t^{1-\alpha}. \quad (3.5.11)$$

Then Ha and Howitt (2007, *ibid*) show that the different generations of R&D-based endogenous growth models can be derived from equation (3.5.10) depending on the parameter restrictions:

The first generation of endogenous growth models (the R/GH/AH models) appears when $\phi = 1$, $\sigma = 0$, and $\beta > 0$, then:

$$g_A = \delta_R \cdot L_{At}^\beta. \quad (3.5.12)$$

In this case, there is no product proliferation ($\sigma = 0$) and no fishing-out ($\phi = 1$), and the growth rate of new ideas, g_A , is proportional to the size of R&D input. This is the case of the first generation of models with “strong scale effect”, the growth rate of TFP and GDP per capita exploding as the population grows.

The semi-endogenous growth class of models (the J/K/S models) require $\phi < 1$, $\sigma = 0$, and $\beta > 0$ and we have

$$g_A = \delta_R \cdot L_{At}^\beta \cdot A_{t-1}^{\phi-1}.$$

There is still no proliferation of products ($\sigma = 0$) but we now have decreasing returns to scale in the

stock of knowledge ($\phi < 1$) such as the growth rate of new ideas is pinned down again by the growth rate of population in the long-run and there is a weak scale effect:

$$g_A = \frac{\beta}{1 - \phi} \cdot n.$$

The second generation of endogenous growth models (the Y/P/AH/DT/H models) finally appears with $\phi = 1$ and $\sigma = 1$ then

$$g_A = \delta_R \cdot \left(\frac{L_{At}}{Z_t} \right)^\beta.$$

As usual for this class of model, now R&D intensity, here the share of the labor force working in the research sector, S_A (if we admit to simplify that $Z_t = L_t$), drives the long-run growth rate. We also remark that by setting β to zero, we will end with the neoclassical growth model of Solow, with technical change growing at the exogenous rate δ_R .

Given the long dynamics that characterize the growth models, that were underlined by Jones (1995a, [179]), the econometric test of the parameter restrictions in equation 3.5.10, imposed by the different classes of models, generally uses an error correction modeling, capturing the influence of the short-run modifications in the level and the growth of the variables entering into the equation, as well as the pattern of their long-run relationships requiring that the different variables are stationary and co-integrated. For that, Ha and Howitt start from the following log-linear approximation for equation 3.5.10, by adding also a disturbance term ε_{1t} , that they assume to be a stationary process of mean zero:

$$\Delta \ln A_t = \ln \delta_R + \beta \cdot \left[\ln L_{At} - \sigma \cdot \ln Z_t + \left(\frac{\phi - 1}{\beta} \right) \cdot \ln A_t \right] + \varepsilon_{1t}. \quad (3.5.13)$$

We see that, if the growth of the stock of new ideas, given by $\Delta \ln A_t$ is stationary, then the expression in brackets in the equation above should be also stationary, as the variable E_t given by

$$E_t = \ln L_{At} - \sigma \cdot \ln Z_t + \left(\frac{\phi - 1}{\beta} \right) \cdot \ln A_t \quad (3.5.14)$$

is stationary. In the semi-endogenous case, $\phi < 1$, $\sigma = 0$ and $\beta > 0$, this implies $E_t = \ln L_{At} + \left(\frac{\phi - 1}{\beta} \right) \cdot \ln A_t$. Therefore, the stationarity of E_t requires that $\ln L_{At}$ and $\ln A_t$ should be integrated at the same order, and if they are not stationary, there should be a co-integration relationship between themselves with as the co-integration vector $\left[1, \frac{\phi - 1}{\beta} \right]$. Now, in the fully-endogenous, we have $\phi = 1$ and $\sigma = 1$ and then $E_t = \ln L_{At} - \ln Z_t$. $\ln L_{At}$ and $\ln Z_t$ should be integrated on the same order, and,

if they are not stationary, be co-integrated with $[1, -1]$ the co-integration vector.

For the econometric test, in this equation, the growth rate of ideas is generally proxied by the growth rate of *TFP*, that can be calculated classically as a Törnqvist index from the equation 3.5.11 for final output. For the research input (L_{At}), it is possible to take the number of persons in the research sector, but other choices are possible, like the real R&D expenditures in monetary units, where following Kortum (1993, [197]), R&D is often divided by A to remove possible scaling effects between R&D and innovation output, like the declining ratio that Ha and Howitt report (2007, *ibid*) between patents and R&D for the US. For the index of product proliferation, Z_t , we can use, for example, the stock of trade marks, the GDP, or simply total employment.

Applying this empirical framework to US data for the 1953-2000 period, Ha and Howitt find strong evidence of co-integration between the GDP and the R&D, with unitary coefficients, in accordance with the Schumpeterian theory. But they could not find strong support to co-integration between the log of the TFP and of the R&D input, as would suggest the semi-endogenous theory. Therefore, for the authors, “(...) *Schumpeterian theory is more consistent with the long-run trends in R&D and TFP than the semi-endogenous theory*” (Ha and Howitt, 2007, *ibid*, page 735). This result is corroborated by the long-run trend of the growth rate in the R&D input, that has decreased threefold without a similar decrease of the rate of TFP growth, as would suggest the semi-endogenous growth theory. On the contrary the observed trend in the R&D intensity remained roughly stable in the United States in the same period, like the growth rate of TFP, as the fully-endogenous growth theory requires. But for Ha and Howitt, “*None of these tests is decisive, especially given the relatively small number of observations for detecting long-run relationships and the possibility that the R&D production function (...) might have shifted over the period*” (Ha and Howitt, 2007, *ibid*, pages 764-765). The very long transitional dynamics in the relation between R&D and productivity may be another difficulty to find econometric support for the semi-endogenous theory. In fact, as Ha and Howitt report on page 764 of their paper, “*Neither theory does much better than a linear-time trend in explaining the time series of productivity (...)*”.

Another methodological problem is this study by Ha and Howitt, that was stressed by Madsen (2008, [228]), is that “*Although co-integration tests of ((3)-(5)) [equation 3.5.14 above] can satisfy one of, or a combination of, the two growth models, they need not imply that TFP growth is explained by either of the models*” (Madsen, 2007, *ibid*, page 4). Therefore, the existence of a co-integration relationship between the variables L_{At} , Z_t and A_t in this equation are necessary but non-sufficient

conditions for either of the models to provide adequate explanations for growth. For that, the model of test must be complemented by a TFP regression. Madsen proposes the following:

$$\Delta \ln TFP_t = \tau \cdot \left(\frac{L_{At}}{Z_t} \right) + \left(\frac{\beta}{1-\phi} \right) \cdot \Delta \ln L_{At} + \gamma \cdot \left(\frac{TFP_{t-1}^{max} - TFP_{t-1}}{TFP_{t-1}} \right) + \varepsilon_{2t} \quad (3.5.15)$$

that includes the Schumpeterian theory from the parameter restrictions $\tau > 0$ and $\frac{\beta}{1-\phi} = 0$ and the semi-endogenous growth model with symmetrically $\tau = 0$ and $\frac{\beta}{1-\phi} < 0$. Note that Madsen enriches the model with the introduction in the equation of a third term, measuring, following Griffith *et al.* (2003, [137], 2004, [138]) and Aghion and Howitt (2006, [5]), the “*distance to the frontier*”, with the idea that the countries that lay behind the technological frontier, represented typically by the level of *TFP* reached in the US, could implement and imitate the technologies of the leaders by investing actively in R&D or/and in human capital. In the equation, TFP_{t-1}^{max} therefore represents the “*leading edge*” technology measured as the highest *TFP* level in the group of countries that are studied, and γ is a positive parameter measuring the speed of convergence towards the technology frontier, that may depend on factors such as institutions, government policy or openness to international trade. This last term is usually multiplied by $\left(\frac{L_{At}}{Z_t} \right)$ in the empirical studies (as in Howitt, 2000, [167]), supporting the view of the Schumpeterian theory that it is necessary to dispose of a minimum absorptive capacity in order to get closer to the technology frontier. Finally, the model also includes international knowledge (or technology) spillovers measured, as in Coe and Helpman (1995, [63]), through the channel of imports, where technology from country j to country i are computed with the following weighting scheme (adapted from Madsen, 2008, *ibid*, page 10):

- $\left(\frac{L_A}{Z_t} \right)_{it}^f = \sum_{j=1}^N m_{ijt} \cdot \left(\frac{L_A}{Z_t} \right)_{jt}^d$, $i \neq j$, in the case of Schumpeterian growth theory, and
- $L_{Ait}^f = \sum_{j=1}^N m_{ijt} \cdot \tilde{L}_{Ajt}^d$, $i \neq j$, in the case of the semi-endogenous growth theory,

where m_{ij} is the share of i 's imports of high technological products from country j , the superscript d and f stand for domestic and foreign, and \tilde{L}_{Ajt} is an index of innovative activity, which is equal to one in 1995, to ensure that large countries do not have a higher weight in the index relative to smaller countries, and with N the number of countries in the panel.

Applying this methodology to a panel of 21 OECD countries on 1970-2004, Madsen (2008, *ibid*, [228]) finds, using various model specifications, estimation methods and indicators for innovative ac-

tivity, that the semi-endogenous growth theory cannot be supported by the data over time and across countries. The Schumpeterian growth theory, is on the contrary, largely consistent with the time-series evidence, the variables measuring innovative activity and product variety being co-integrated, and R&D intensity Granger-causing *TFP* growth. The *TFP* growth is also positively related to the distance from the technology frontier, which is also consistent with the Schumpeterian growth theory. The limit is however that the Schumpeterian theory is not able to adequately account for cross-country *TFP* growth rates, from these estimation results.

The results by Barcenilla-Visús, López-Pueyo and Sanaú-Villarroya (2010, [19]), that use a similar framework as Madsen (2008, *ibid*), transpose at sectorial level for 6 OECD countries and 10 manufacturing industries for the period 1979-2001, are more mitigated. Contrary to Madsen (1998, *ibid*) and Ha and Howitt (2007, *ibid*) they find strong support for the semi-endogenous growth theory, while the Schumpeterian model only finds support from the high impact of the distance to the frontier variable, which represents the autonomous technology frontier. Kruse-Andersen (2017, [201]) that extends the initial framework of Ha and Howitt (2007, [153]) by estimating a full VAR model involving one equation for TFP, one for product varieties, and one for innovative activity, no longer finds support for the Schumpeterian model that he applies to US data too for the period 1953-2000. The fully endogenous variety is rejected by the empirical evidence, while, in contrast, the empirical results support the semi-endogenous model. Therefore, for Kruse-Andersen (2017, *ibid*), these results contrast with those in many other studies, where the support for the Schumpeterian theory seems to result from specification biases. These include, at macro level Laincz and Peretto (2006, [204]), Ha and Howitt (2007, [153]), Madsen (2008, [228]), and at firm level Ulku (2007, [315]) and Venturini (2012, [324]).

So is the growth endogenous, semi-endogenous or both?

Even though we did not survey all the literature aiming at testing for the semi-endogenous and fully endogenous growth hypotheses, we see that the tests are not very conclusive. Many factors can explain this difficulty to get clear-cut results.

We first illustrated by the findings of the theoretical models presented above, the fact that the knife-edge conditions, required by fully endogenous growth to emerge victorious from these tests, are very restrictive. The general case, as illustrated by Li (2000, *ibid*), is the semi-endogenous one. Therefore, even in the models admitting the possibility for fully endogenous growth, the proliferation of products that the majority includes, links part of the long-run growth with the exogenous growth rate of population. It is therefore not surprising that the tests of the models, have difficulties in discriminating

between the two facets of growth: one coming from the increase in the number of persons that engage in research, shifting the technological frontier, and one reflecting the effort of individuals, firms or countries, to transform the knowledge created in innovations.

The literature on R&D and productivity (chapter 2) demonstrates that pure knowledge externalities are the main drivers of innovation and TFP growth, but that it requires sufficient absorptive capacity to be effective. Technology transfers and rent spillovers also have strong “*equalizing*” effects on the growth rate of different countries. Howitt (2000, [167], 2004, [260]) points out, that when introducing cross-industry and cross-country knowledge externalities and technology transfers in the models, “(...) *what matters [finally] for a country growth rate is the configuration of R&D throughout the world, not just in that country. Thus [pursues Howitt] there is nothing that a relatively small country like Canada, that performs only a small fraction of the world’s R&D, can do to influence its long-run growth rate. [But] The same is not true (however) for the United States, which is large enough that changes in its R&D intensity can have a significant effect on the rate of progress of the global technology frontier*” (Howitt, 2004, page 6).

Another problem is the long dynamics that are implied by the growth models. Returning to the case of United-States, Fernald and Jones (2014, [118]) show that while the US has acknowledged a remarkable and surprising constancy with its growth rate of GDP per capita, from 1870s to the present, close to 2 percent, it was nevertheless marked by strong transitional dynamics. Taking again the example of the post-WW II period for which we have data, when performing a growth accounting exercise, Fernald and Jones show that “*In sum, the accounting implies that growth over the past 50 years largely reflected transitory factors*” (Fernald and Jones, *ibid*, page 3). Huge changes have occurred, notably in educational attainment, the US economy R&D intensity and population growth, and the growth rate of the US economy over the period could be explained for 21% by the rise in the R&D input, as in J/K/S semi-endogenous growth models, for 58% by the rise in the R&D intensity, like in the Y/P/AH/DT/H fully-endogenous growth models, for 20% by the rise of Human Capital, like in the Lucas (1988, [225]) model, and for 0% by capital deepening, like in the Solow (1956, [300]) model. These findings are not proof that the fully endogenous growth model better explains the post-war growth in the US, than the semi-endogenous one, but it confirms that an the increase in the size of the research sector and a rise in the R&D intensity are important for the long-run growth.

3.6 The role of structural change and out-of-equilibrium growth

Empirical testing of endogenous growth models is therefore made difficult by the transitional dynamics already described by Jones in his two 1995 papers, and by our inability to “observe” the steady states on which the protocol of test of these models is based. This difficulty is reinforced by what Aghion and Howitt call the “*tyranny of numbers*” (Aghion and Howitt, 2009, [9], page 109). The quality change in products over years makes it difficult to separate the influence on growth of capital accumulation and of innovations. Therefore, as already discussed in chapter 2, if technological progress is embodied in new capital, but not properly reflected in national accounts, it will bias both the measurement of TFP and of capital. The situation is even worse as growth is not, like in most of the NGT models, a process where all the sectors of the economy grow at the same rate. On the contrary it is a process where the progressive sectors, that innovate more, will grow faster than the other sectors of the economy. The NGT models also focus on the supply side, while the demand aspects are also very important because of Engel effects that induce profound modifications in the categories of goods that are consumed. There are strong structural changes, with some sectors growing faster than others, the emergence of new sectors and the disappearance of old ones. The problem is even more pronounced as most of the goods and services we consume today did not exist one, or half a century ago. And the rising size of the service sectors, and of the public one, where the output is very difficult to measure, increases the difficulty. So, the measurement of output and *TFP* growth remains a problem, especially for the inter-temporal comparisons requested by the empirical testing of the NGT models. For example, is the R&D input adequately measured, that is to say the quality of the skills of doctors, engineers and technicians, and of the capital goods that are used in research that account for about half of R&D expenditure?

Concerning structural change, some models tried to introduce such features in the NGT models, with the notion of General Purpose Technologies (GPT), first introduced by Bresnahan and Trajtenberg (1995, [43]). A GPT is defined as a disruptive technological innovation, that affects production and/or innovation in many sectors of the economy. The classical example of such technologies are the arrival of the steam engine, electric power, computer and now Information Technologies (IT). As Helpman and Trajtenberg explain (1998, [160]), these technologies need an entirely new set of intermediate inputs before they can be implemented and used. There is a lapse of time between the initial investment in research and development, and the first industrial applications of technology. For example, David (1990, [92]) shows in the case of electricity, it may take several decades, between, the arrival of a new

GPT and its first beneficial effects on TFP and output growth. In the initial phases of development of a GPT, growth could even decrease, as resources are taken away from production and put into R&D activities, while their industrial applications remain limited. These first negative effects are reinforced as the introduction of the new GPT will have deep creative destruction effects, accelerating the scrapping of human and physical capital stocks. On the other hand, to become efficient, the new GPT needs the introduction of complementary innovations and the development of new skills. For the case of the IT, these time lags were certainly at the origin of the initial decline in productivity growth in the 1970s and the 1980s, illustrated by the famous Solow (1987, [302]) paradox: *"You can see the computer age everywhere but in the productivity statistics"*.

This *"time so build"*, and the long transitional dynamics and structural change implied by the setting of a new technology paradigm, therefore underline some of the limits of the NGT models, that focus mostly on the long-run steady states, and where little room is made for structural change. Some models make a step in that direction, with the introduction of the notion of GPT, but other limitations exist that reinforce the difficulty to find strong empirical validation to support these models.

There is notably the assumption that there is only one technological trajectory. If for example we take the semi-endogenous growth model of Jones (1995b, [180]), the new variety of products will arrive with the following technology:

$$\Delta A_t = \delta \cdot A_{t-1}^\phi \cdot L_{A_t}^\lambda$$

like in equation 3.4.5 above. But as Cozzi (1997, [79]) underlines for example, *"The literature on innovation offers evidence of qualitatively different technological paradigms (Dosi, 1982, [107], 1984, [108]) and of technological trajectories (Nelson and Winter, 1977, [245]). (...) The inevitable presence of unappropriable spillovers, technological interrelatedness, dynamic increasing returns, learning by using, and network externalities (David, 1985, [91]; Arthur, 1989, [16]) imply that the market mechanisms can give no guarantee that the trajectory with the long-term prospects will readily be selected: therefore, relatively inferior technology lock-ins may not be confined to QWERTY keyboards, DOS computers, VHS videocassette recordings, light-water reactors for nuclear plants, and so on (Foray and Freeman, 1993, [119])"* (Cozzi, 1997, *ibid*, pages 385-386).

We can therefore oppose to the *"one technology"* framework of Jones (1995b, *ibid*, [183]) with the change that there are now T possible technologies for producing the new varieties of goods

$$\Delta A_{it} = \delta_i \cdot A_{it-1}^{\phi_i} \cdot L_{Ait} \quad (3.6.1)$$

with $i = 1, \dots, T$, the choice of different technologies, $\delta_i > 0$ and $\phi_i \in [0, 1)$ the parameters and L_{Ait} the amount of labor services hired in the i th R&D sector at time t . Therefore, as Cozzi explains, each line of innovation has different inter-temporal externalities, and the more a trajectory i will be explored, the cheaper it will become to explore it, independently of the size of the productivity parameter δ_i . Therefore, the economy could inefficiently shift away from research paths that are at the beginning difficult (low δ) but that generate large knowledge spillovers (high ϕ) and definitively lock on these inferior technologies. We see that this modification, while retaining the policy implications of the initial model, allows for additional policies by taxing and subsidizing trajectories to redirect toward the good one. Finally the consequence is that the *TFP* growth measured at the aggregate level, and its relationship with R&D investment, will be influenced by the performance of the technological trajectories taken by the different sectors of the economy.

Another limitation of the NGT models are the strong assumptions that these models have concerning households and firms behavior and expectations. Firms and consumers are supposed to have perfect foresight, production functions are of the Cobb-Douglas type and the Keynes-Ramsey consumers have unitary inter-temporal substitution elasticities, ensuring that the economy will always converge towards the steady state. For authors like Amendola and Gaffard (2014, [13]) , by focusing only on long-run equilibrium, we miss “(...) *identifying the real nature of production processes [that] is essential for understanding the out-of-equilibrium process in which consists the dynamic of the economy*” (Amendola and Gaffard, 2014, *ibid*, page 19). Therefore, a qualitative change is implied whenever a structural modification is involved, and innovations are the foremost examples of these changes. “*In all cases, the previously existing productive structure is disturbed, its way of functioning is affected and as a result a problem of inter-temporal complementarity arises which calls for co-ordination over time of production processes to render the process of change undertaken viable. The focus must therefore be in the first place on the time structure of production processes*” (Amendola and Gaffard, 2014, *ibid*, same page).

For the authors, in echo to the GPT and creative destruction concepts, it is a qualitative change, as opposed to a mere quantitative growth at equilibrium like in the NGT models, that “(...) *implies instead a change in the way of functioning in the economic entity considered (the economy or the firm), that is, a structural modification which, according to the above definition, is characterized by a change*

in the balance between processes in the phase of construction and processes in the phase of utilization, and hence a change in the age structure of productive capacity with respect to its previous equilibrium configuration. (...) Not only construction and utilization, but also investment and consumption, and supply and demand, are then no longer harmonized over time". (Amendola and Gaffard, 2014, *ibid*, page 22) In the standard analysis, efficiency is pursued and the mere appearance of a "superior" technique pushes to its adoption. Adoption is therefore treated within an equilibrium framework, where it is instantaneous and "*(...) does not allow the transition phase during which productive capacity necessarily gets distorted to show-up*" (Amendola and Gaffard, 2014, *ibid*, page 23).

Finally is long-run growth endogenous, semi-endogenous, or both? We have seen that it may be both, and that both features are present in the statistics, but this debate on endogenous/semi-endogenous growth is perhaps less important than trying to understand how the economy functions during these long periods of out-of-equilibrium growth.

3.7 New Growth Theories and New Kaldor facts

The exploration of the NGT models that we proposed in this chapter do not pretend to be exhaustive. It focused on the presentation of the main concepts underlying these models, that perpetuate the neoclassical model of growth. Our interest was therefore to mainly focus on the notions of semi-endogenous versus fully-endogenous growth, that we find also at the core of the macro simulation models used by the European Commission for the evaluation of its R&I policies. We will now briefly present other developments of these new growth theories and, then, to end on a positive touch, we will conclude on the contribution they bring to understanding the modern economic growth process. For this we study these two points with the help of two papers by Howitt (2004, [260]) "*Endogenous Growth, Productivity and Economic Policy: A Progress Report*" and Akcigit (2017, [12]) "*Economic Growth: The Past, the Present, and the future*", and one paper by Jones and Romer (2010, [181]), already used at the beginning of this chapter, "*The New Kaldor Facts: Ideas, Institutions, Population, and Human Capital*".

Among other important developments of the NGT theories, we must first quote the works that have aimed at dealing with the traditional trade-off that still opposes authors, between static efficiency, that returns to Adam Smith's invisible hand, and the Schumpeterian dynamic innovation, highlighting the competition's negative impact on innovation. The economic implications of these two traditions

were already analyzed in detail, for example by Loury (1979, [224]) and Kamien and Schwartz (1972, [190]1976, [191]), with these two main ideas: Following Schumpeter (1942, [294]), a monopoly gives entrepreneurs the greatest incentive to invest in innovation, it is the “Schumpeterian effect”, but, on the other hand, there is the “escape effect”, that shows that in certain circumstances, higher competition will have a positive impact on innovation, with firms trying to innovate in order to escape from competition. For these authors, there should be therefore a “trade-off” between these two effects, with the idea that there is an optimal level of competition, that is supposed to follow an inverted-U shaped curve, where at the top the incentive to innovate is at its maximum.

While in the NGT models the incentive and the reward for innovation are monopoly rents, Aghion, Harris, Howitt and Vickers (2001, [7]) have re-examined this old debate, by introducing not only the absolute rents that are obtained by successful innovators, but also the incremental rents, that is to say the difference between the level of profit between a firm that innovates, and one which does not, into the model. These authors notably show that while the intensity of competition tends to reduce the profits of innovators, it also reduces the profit of non-successful innovators by even more. Aghion, Bloom, Blundell, Griffith and Howitt (2003, [6]) have tested this theoretical result with an empirical study on UK manufacturing industries, confirming the prediction of this inverse-U effect of competition on innovation and growth. As Howitt explains (2004, [260]), the reason for this result is that there is little incentive to innovate when there is little competition, “(...) *because firms in such industries can earn a lot of profits even without having to innovate. Innovation will also be low in industries where there is so much competition that once one firm establishes a technological lead the followers are discouraged by their inability to earn profits until they have climbed into the lead themselves, and (...) the leader does not have to innovate very frequently in order to retain the deal*”. (Howitt, 2004, *ibid*, page 10). Then, for Howitt, “*innovations typically takes place more rapidly at some intermediary degree of competition between these two extremes*”. This role of competition for innovation has therefore placed the debate on the role played by patent protection in the growth process. Therefore, if innovations are not protected, and could be imitated without effort and penalty, the incentive to innovate would disappear. As a result, the models nevertheless show that a little imitation has always the effect of raising the long-run growth rate of innovation and consequently of economic growth.

Another important improvement comes from the introduction of firms heterogeneity. In the early models, all innovations are made by new entrants, that either introduce new products, or improve the quality of the old ones. The impossibility of incumbent firms to innovate themselves was therefore at

odds with the observation of real panels of firms at the micro level, like the consequence of these models where the exit rate of firms was independent of their size and age. Klette and Kortum (2004, [194]) at first fixed some of these problems by describing firms as a collection of different production units, that can grow by improving old products from other firms. Akcigit and Kerre (2017, [11]) developed this framework further by “(...) allowing firms to improve not only other firms’ products through ‘external innovations’, but also their own products through ‘internal innovation’” (Akcigit, 2017, *ibid*, page 17). Akcigit reports that “(...) the model allows to generate a close fit to the firm- and innovation-level data from the U.S. Census Bureau and the U.S. Patent Office (...) [showing] that small firms are spending disproportionately more effort to do external innovations, and the spillovers associated with the external innovations are significantly larger”. The introduction of heterogeneity between firms and individuals in the model, and the possibility to calibrate them with micro data to which they can also be exposed, therefore looks like a fruitful development that should involve a lot of research in the future.

We see that the theoretical literature on growth continues to expand fast, but helped by the increasing availability of data, and the rise of the computational power. But finally what does the progress of NGT theories represent, compared to the initial neoclassical model of growth?

To examine this last question we will return to the article by Jones and Romer (2010, [181]), already used for illustrating the progress that the model of Solow represented, to explain the six Kaldor “stylized” facts. That was for the 1950s and the early 1960s, but for Jones and Romer, six “*new Kaldor facts*” have emerged that the models should explain:

1. The increase of the size of the market and globalization. World trade nearly doubles from the 1960s, with “*a much larger increase in the economic integration*”, as attested, for example, by the share of Foreign Direct Investment in GDP that has grown “*by a factor of 30*”.
2. The acceleration of growth. This is a long-run phenomenon and “*For thousands of years, growth in both population and per capita GDP has accelerated, rising from virtually zero to the relatively rapid rates observed in the last century*”.
3. The variation in modern growth rates, and “*The variation of growth of per capita GDP increases with the distance from the technology frontier*”.
4. Large income and TFP differences, and “*differences in measured inputs explain less than half of the enormous cross-country differences in per capita GDP*”. Therefore poor countries are not

poor only because they have less human and physical capital, but also because they use it less efficiently than richer countries.

5. Rising human capital, that is observed all around the world.
6. Long-run stability of relative wages, and *"The rising quantity of human capital relative to unskilled labor has not been matched by a sustained decline in its relative price"*.

Then, for Jones and Romer (*ibid*, pages 241-242), *"Whereas Kaldor's original facts were explained almost entirely using the neoclassical growth model, the facts we highlight reveal the broader reach of modern growth theory. To capture these facts, a growth model must consider the interaction between ideas, institutions, population, and human capital. Two of the major facts of growth - its acceleration over the very long-run and the extraordinary rise in the extent of the market associated with globalization - are readily understood as reflecting the defining characteristic of ideas, their non-rivalry. The next two major facts - the enormous income and TFP differences across countries, as well as the stunning variation in growth rates for countries far behind the technology frontier - testify to the importance of institutions and institutional change. Our final two facts parallel two of Kaldor's original observations, but while his emphasis was on physical capital, the emphasis in modern growth theory is on human capital. Human capital per worker is rising rapidly, and this occurs despite no systematic trend in the wage premium associated with education"*.

We have seen the scope of the progress that the NGT have accomplished, that puts all these facts in an unified framework, that the applied macro models used by the European Commission aim to do, and this is what we will explore in the next chapter.

Part II

The Macro Models Used by the European Commission

Chapter 4

The endogenization of innovation on R&D

Chapter 4. The endogenization of innovation on R&D

Four macro simulation models are currently available for the evaluation of European Commission Research and Innovation (R&I) policies: QUEST ([322]), NEMESIS, RHOMOLO ([212]) and GEM-E3 ([110]).

NEMESIS with GEM-E3¹ were, historically, the first large scale models for the EU economy integrating an endogenous representation of technical change and innovation. Fougeyrollas *et al.* (see *e.g.* Fougeyrollas *et al.* 2005, [121]), achieved the first integration of endogenous technical change in GEM-E3 at the end of the 90's. From 2000, NEMESIS was developed by an European research consortium led by the ERASME laboratory², in order to analyze the macro-sectorial impacts of European structural policies. A first operational version was available in 2002. While NEMESIS has continued to improve the representation of innovation in every productive sector, GEM-E3 became progressively specialized, by the University of Athens, in energy technologies. In the mid-2000s, an endogenous representation of technical change was also included in QUEST (see Roeger *et alii*, 2008 [281]), a model developed by the Directorate-General for Economic and Social Affairs (DG ECFIN) of the European Commission. More recently, RHOMOLO (see Lecca and Sakkas, 2018, [212]), developed from 2010 by the Directorate General Joint Research Center (DG JRC), in collaboration with the Directorate General for Regional and Urban Policy (DG REGIO), was updated to include an operational version with endogenous technical change.

We see from the table 4.0.1, that the four models belong to different families and different economic traditions.

QUEST is a Dynamic Stochastic General Equilibrium Model (DSGE), more in line with the canons of modern macro-economic theory. From new Keynesian inspiration, it is grounded on microeconomic foundations derived from inter-temporal utility and profit optimization. There is perfect foresight and infinite live consumers, which make the model fully dynamic and forward looking. It also assumes monopolistic competition. Its overall structure is very close to the theoretical models, like the ones reviewed in the chapter 3, where policy shocks are analyzed as the transition from a long-run steady state general equilibrium to another. The model was intensively used by the DG ECFIN to analyze the impact of fiscal and structural policy reforms and assess the impact of EU Cohesion Policy.

RHOMOLO is a Spatial Computable General Equilibrium Model (SGEM). It covers 27 EU countries

¹It is a model developed and managed by the National Technical University of Athens (NTUA).

²The ERASME laboratory (now SEURECO) from École Centrale Paris and University of Paris I Sorbonne, the Federal Planning Bureau of Belgium, the E3M3 lab. / ICCS /NTUA and the Chambre d'Industrie et de Commerce de Paris.

Table 4.0.1 – General characteristics of QUEST, RHOMOLO, GEM-E3 and NEMESIS

Model:	QUEST	RHOMOLO	GEM-E3	NEMESIS
1 – Model type	DSGE	SCGE	CGE	Macro-econometric
2 – Multi-country	EU-28+RoW	EU-27+RoW	EU+RoW5	EU-28+RoW
geo-units	countries	NUTS2 regions	country groups	countries
3 – No of sectors / competition	1 monopolistic competition	6 monopolistic competition	38 perfect competition	30 monopolistic competition
4 – Inter temporal optimisation	Yes / fully dynamic	No / recursively dynamic	No / recursively dynamic	No / recursively dynamic
5 – Parameterisation	Stochastically estimated & calibrated	Structurally estimated & calibrated	Structurally estimated & calibrated	Structurally estimated & calibrated

Source: Adapted from Di Comite and Kancs, 2015 ([99])

on a very detailed geographical level (NUTS2 level) which represents 264 EU regions. The model is used for impact assessment and provides sector-, region-, and time-specific simulations to support EU investment and reforms covering a wide range of policies. It includes 10 competitive sectors where industry is regrouped in one; a subset of these sectors operates under monopolistic competition, and the rest under perfect competition. RHOMOLO has a micro-funded general equilibrium approach, but saving and interest rates are exogenous in the model. There is no perfect foresight and the model is recursive dynamic.

GEM-E3 is a Computable General Equilibrium Model (CGE) with a particular focus on energy and environmental issues, covering the key interactions between the economy, the energy system and the environment. It distinguishes between six country groups, including both developed (the EU-28, North America, OECD Pacific) and developing economies (China, Energy Exporters, Rest of the World). The model splits the entire economy into 38 production sectors (of which 10 are specifically for the power generation sector). In GEM-E3 the sectors are considered perfectly competitive, anticipations are adaptative and the model is recursive dynamic. The model is “flexible” as it allows for capital mobility between sectors and world regions, and the savings and interest rates are endogenous. Applications of the model have been carried out for several Directorates General of the European Commission (economic affairs, competition, environment, taxation, research), particularly with regard to the economics of climate change.

NEMESIS models each EU-28 country with 30 distinct economic sectors that interact with the regions in the rest of the world. It is macro-econometric, follows a neo-Keyesian theoretical approach,

and does not explicitly represent the utility maximization behavior of households, although consumption functions are implicitly derived from this behavior. It is based on structural equations that are estimated econometrically, which means the model relies on long-run time series and a solid empirical base. The model includes various time lag structures and the possibility of disequilibrium of the labor and capital markets, which implies the relaxation of the equilibrium constraints that are present in the other models. Expectations are adaptative, and the dynamic of the model is recursive. The sectors are assumed to operate under monopolistic competition, and wage formation results from a wage bargaining problem equivalent to an augmented Phillips curve.

The seminal works using NEMESIS for the evaluation of R&I policies has focused on the 3% R&D effort of the Lisbon Strategy (Brécard *et al.*, 2004, [41] and Brécard *et al.*, 2006, [40]). This first study was followed by the assessment of the RTD National Action Plans related to the Barcelona Objective (Chevallier *et al.*, 2006, [57]). Then NEMESIS was more directly used for ex-ante impact assessments of the European Framework Programmes (FP) for Research and Innovation. In 2005, it was mobilized by the European Commission for the ex-ante assessment of FP7 (EC, 2005, [69]; Delanghe and Muldur, 2007, [98]) and then, from 2010 to 2013, for the annual ex-ante assessment of the FP7 calls for proposals (Fougeyrollas *et al.*, 2010, [123], 2011, [124]; Zagamé *et al.*, 2012, [336]). For the more recent applications of the model, we can finally quote the ex-ante evaluations of H2020 (EC, 2012 – Annex 5, [115]) and of the post-H2020 “*Horizon Europe*” (EC, 2018, [72], and Boitier *et al.*, 2018, [34]) programmes, the ex-post evaluation of FP7, and the interim evaluation of H2020 (PPMI, 2017, [272]; EC, 2017, [71]).

As NEMESIS developed this important track record for the evaluation of EC R&I policies, the necessity to diversify the modeling approach soon became evident. It is apparent from the general characteristics of the models that are currently used by the DG Research, that NEMESIS cannot answer all the questions. It is sectorially more detailed than QUEST and RHOMOLO, and it includes many channels of structural change to depict the in-depth transformations of economic activities and of allocation of labor between the different sectors. But NEMESIS has limitations, and its spatial dimension (Country level) makes RHOMOLO (264 EU regions) more adapted for studying, for example, the socioeconomic and regional impacts of structural funds, and notably of the share financing R&I and human capital formation (about 15% of these funds under current trends). NEMESIS has limitations concerning energy technologies, that are not explicitly represented, whereas in GEM-E3 the adoption and development of these technologies are endogenous and detailed. Furthermore the out-of-equilibrium

approach followed in NEMESIS, does not ensure that results, even in the “long-run”, would conform the general equilibrium prerequisite at the core of the QUEST model of the DG ECFIN. Therefore, as Blanchard recently underlined in a more general context (2017, [31]), the different classes of models are complementary. They have a lot to learn from each other and, if it were possible, it would be counterproductive to try to embody all the models in an unified framework. “*No model can be all things to all people*” (Blanchard, *ibid*, page 43).

To respond to this need of diversity, the Joint Research Center (JRC) of the European Commission, that supports more than 20 policy Directorates-general of the European Commission for policy implementation and evaluation, has created many initiatives for developing the panel of available tools, and add value to policy-making. The unit of the JRC in Sevilla, the IPTS (the Institute for Prospective Technological Studies) has for example coordinated the development of the RHOMOLO model, and has developed international collaborations in order to improve the existing toolkit for the assessment of European innovation policy. For illustration, a conference was organized in March 2017 at DG Research by the JRC in association with the International Economic Association, to discuss the characteristics of the models that are currently used by the European Commission (with a focus on RHOMOLO, QUEST and NEMESIS), and on the possible avenues for improving the modeling of R&I investments and their impact³. The publication of a book at Palgrave-McMillan, “*Macroeconomic Modelling of Innovation Policy*” (2019, [10]), resulted from this workshop.

There is a need for independent and diversified expertise at the European Commission, and several research projects were finally financed, under the H2020 programme by DG Research, to adapt additional models for the analysis of R&I policies. The project FRAME⁴ (Framework for the Analysis of Research and Adoption Activities and their Macroeconomic Effects), coordinated by the university of Mannheim, should provide a “*new generation*” of the DSGE model, that would include new features such as the distinction between investment by companies in R&D and their investment in technology adoption. The model should be also multi-sector and multi-country. The project MONROE⁵, coordinated by the Netherlands Environmental Assessment Agency (PBL), aims at developing a “*modeling toolkit*” and an “*interactive online tool*” allowing European and national governments, academia, regional and local bodies to quantitatively evaluate the impact of their specific research programmes and

³With the participation of Philippe Aghion, Francisco Buera, Guido Cozzi, Felipe Saffie, Petr Sedlacek, Omar Lican-dro, Jacques Mairesse and Ufuk Akcigit.

⁴see: <https://www.h2020frame.eu/frame/home.html>

⁵see: <https://www.monroeproject.eu/>

innovation policies. This toolkit will use existing models⁶ that will be developed to include endogenous growth and innovation mechanisms.

We see that there are many potential “entrants” in the field of the macroeconomic modeling of innovation policies in Europe, but there is also room for innovation and improvement in the incumbent models, as we will show in the next chapter focusing on NEMESIS. We limit the presentation in this chapter to the QUEST, NEMESIS and RHOMOLO models, we just briefly introduced here. The model GEM-E3 is left aside as it is directed towards energy and environmental technologies that belong to specific modeling traditions. Other models currently in development are also ignored, as they are not yet operational for the evaluation of R&I policies, and there is no reliable or existing documentation on them. After the presentation of the three models in a first section, in a second section we compare the ex-ante evaluation by the three models of the next EU R&I programme, Horizon Europe (for 2021-2027). It is the first time different models were used and their results compared, and it therefore provides a first illustration of the future of macroeconomic impact assessment of EC R&I policies, that should henceforth rely on diverse and complementary expertise.

4.1 QUEST, NEMESIS and RHOMOLO

While the three models that are used for macro evaluation of EC R&I policy belong to different economic traditions and use different scopes of analysis in the way they represent innovation, they all refer, explicitly or implicitly, to the main findings in the empirical literature on R&D, surveyed in the chapter 2, and to the NGT representations, presented in the chapter 3. As proof, in these models, innovations result from investment in R&D only, while there are other channels through which innovations appear, for instance investment in human capital, in enabling technologies such as ICT and software, in other forms of intangibles such as trademarks and other intellectual property rights, etc. NEMESIS embeds several of these in its latest version that will be introduced in the next chapter, restricting us, here, for this comparison, to the version of the model with “R&D only”.

The main difficulty when passing from the theoretical representations of growth analyzed in chapter 3, to the large scale operational models used for policy evaluation, is that the latter are more detailed

⁶There will be the new DSGE model for Europe, the E3ME model (Cambridge Econometrics) that is macro-econometric and has a general outline close to NEMESIS, the PACE model (Mannheim) that is a general equilibrium model similar to GEM-E3, the EU-EMS (European Economic Modeling system) of the PBL that is like RHOMOLO a SGEM model, and the GEM-E3-MONROE model that will propose an extended version of the GEM-E3 model.

than the former: they all have an international dimension (individual EU countries), NEMESIS and RHOMOLO have also a sectorial dimension, and RHOMOLO has a spacial resolution as well (NUTS 2 regions) based on modern geographic economics. Depending on the scope of the models and their level of detail, the passage from theory to “empirics” is therefore more or less straightforward. What is more, this difficulty is reinforced by the fact that not all the models refer explicitly to the NGT.

QUEST, very close, from its aggregate general equilibrium structure, to the theoretical models of growth, is the only model that refers explicitly to the NGT. Its approach, as we will see, is the semi-endogenous growth in Jones’ 1995 paper (1995b, [180]).

In the case of NEMESIS, the representation of technical change was not based, at the time of its construction in the early 2000s, with explicit reference to the NGT. The aim was more pragmatic, to try to reproduce the main findings of the econometric literature on R&D and productivity, surveyed in the chapter 2, in the model. Endogenous innovation is implemented at a sectorial level, and the structural change that it creates in the model, makes it difficult to characterize its growth properties at the macro level. For a given sector, the mechanisms are otherwise similar to those of the second generation of fully endogenous growth models.

Once again the approach is different in RHOMOLO, where the R&D decision is not endogenous and the endogenization of technical change not yet to be achieved. The link that is introduced, at the level of a sector, between the *TFP* growth rate and the rate of growth of R&D investments, refers, like for QUEST, to the semi-endogenous class of models.

Below we present in detail the three models⁷ starting from QUEST up to RHOMOLO. At first, we describe the general features of the models, then we detail the modeling of R&D and innovation, notably of the central elements at the core of the empirical and theoretical literature: The representation of knowledge spillovers, the production function of innovations, and the impact of innovations on economic performance.

4.1.1 The QUEST III DSGE model

QUEST III is a DSGE model from the Directorate-General for Economic and Financial Affairs (DG ECFIN). There is one model for every EU-28 country in interaction with regions of the rest of the world. The model captures both investments in tangibles (physical capital) and intangibles (R&D),

⁷This presentation uses as its main source the book “*The Macroeconomic Modeling of Innovation Policies*” (2019, [10]), that includes a detailed description of the three models in their latest version.

and distinguishes three categories of employment depending on the level of educational attainment. High-skilled workers (ISCED⁸ 8, occupations 21, 22, 31, 32) are the fragment of the labor force that can be employed in the R&D sector (scientists and engineers). The low-skilled labor corresponds to the international standard classification ISCED 0-2 (Lower secondary education or second stage of basic education), the remaining the labor force being defined as medium-skilled. The modeling of innovation is adapted from the semi-endogenous approach of Jones (1995b, [180]) based on the Romer (1990, [284]) product quality model, with the addition of mark-ups for the final goods sector and entry costs for the intermediate sector. The equations of the model are derived from inter-temporal optimization under technological, institutional and budgetary constraints, while the introduction of nominal, real and financial frictions allow to fit the data. There are two types of households, liquidity and non liquidity constrained, and the model also includes a monetary authority that applies a Taylor-type decision rule. Regarding its relations with other countries and regions, the final goods sector produces differentiated goods which are imperfect substitutes for goods produced abroad. Exchanges with foreign countries are also extended to the exchange of scientific and technological knowledge.

4.1.2 Overview of the model functioning

The model is populated by households, final and intermediate goods producing firms, a research industry, a monetary and a fiscal authority.

There are two categories of households, those that are liquidity constrained, and those that are not. Liquidity constrained households do not have access to financial markets and consume all their disposable income at each period. Liquidity unconstrained households are of the Ramsey (1928, [275]) type. They can buy and sell domestic and foreign assets (government bonds), accumulate physical capital they rent to the intermediate sector, and buy the patents or designs produced by the R&D sector, to license them to intermediate firms.

The members of both types of household offer, low-, medium-, and high-skilled labor services to unions that act as wage setters in monopolistically competitive labor markets. Within each skill group, a variety of labor services are supplied which imperfectly substitute each other (*CES* employment aggregate - labor supply). The trade unions charge a mark-up over the reservation wage, and the net real wage to which the mark-up adjusted reservation wage is equated is the gross wage adjusted for

⁸United Nations International Standard Classification of Education.

labour taxes, consumption taxes and unemployment benefits, which act as a subsidy for leisure.

On the firms side, the final output producers use labor aggregate L_{Yt} , and Cobb-Douglas technology, subject to a fixed cost FC_Y and overhead labor FC_L

$$Y_t = (L_{Yt} - FC_L)^\alpha \cdot \left(\sum_{i=1}^{A_t} x_{it}^\theta \right)^{\frac{1-\alpha}{\theta}} \cdot KG_t - FC_Y, 0 < \theta < 1 \quad (4.1.1)$$

with A_t the number of varieties of intermediate inputs x_{it} that combine with an elasticity of substitution of $\frac{1}{1-\theta}$, and KG_t an index of the public capital stock. In equation 4.1.1 L_{Yt} is itself a CES aggregate of the three types of labor that are used in the final goods sector, L_{Lt} , L_{Mt} and L_{Ht} that respectively denote the employment of low-, medium- and high-skilled labor.

In the intermediate sector, monopolistically competitive firms enter the market by licensing a design for domestic households and by making an initial payment FC_A to overcome administrative barriers. Capital inputs are also rented to the household sector for a rental rate i_{kt} . Then, each unit of capital can be transformed into a single input of an intermediate input, exactly as in the initial model of Romer (1990), [284]. The new designs are the output of the R&D sector, that we will detail later on.

On the policy side, public consumption (G_t), investment (IG_t) and transfers (TR_t) from the government are proportional to GDP, while unemployment benefits (BEN_t) are indexed to wages. The government provides subsidies (SUB_t) on physical capital and R&D investments to firms in the form of tax credits and depreciation allowances. Government revenues (R_t^G) are made up of taxes on consumption as well as capital and income. Labor taxes are influenced by the debt to GDP ratio. Finally, monetary policy is modeled via the following Taylor rule, which allows for a degree of smoothing of the interest rate in response to the inflation and output gap,

$$\dot{i}_t = \gamma_{ilag} \cdot i_{t-1} + (1 - \gamma_{ilag}) \cdot (r_{EQ} + \pi_{TAR} + \gamma_{inf}) \cdot (\pi_{Ct} - \pi_{TAR}) + \gamma_{ygap} \cdot \hat{y}_t \quad (4.1.2)$$

The central bank has a constant inflation target (π_{TAR}) and adjusts interest rates whenever actual consumer price inflation (π_{Ct}) deviates from target. It also responds to the output gap (\hat{y}_t) via the corresponding γ_{inf} and γ_{ygap} coefficients. There is also some inertia in the nominal interest rate determined by γ_{ilag} , both with respect to its past and the equilibrium real interest rate (r_{EQ}).

For trade, it is assumed that households, the government and the final goods sector have identical preferences across goods used for private consumption, investment and public expenditure. The separation between goods that are produced domestically and imported is therefore achieved classically from

a *CES* aggregator summarizing the preferences of households, investors and government concerning the origin (domestic or foreign) of the goods they are using.

This short overview of QUEST confirms that, besides its openness to international trade, the introduction of fix costs, of short term nominal, real and financial frictions, and of a monetary authority, the model reflects many features of the *RCK* general equilibrium class of models we presented in chapter 3. It fits in with the modern macroeconomic theory of which the DSGE models are one of the foremost representatives.

4.1.2.1 Modeling of innovation and endogenous growth characteristics

This section more closely examines the characteristics of the endogenous growth mechanisms of the model. To simplify we will return to the presentation in terms of the $F(\cdot)$ and $G(\cdot)$ functions, for respectively final output and the production of new ideas, we already used in chapter 3 (section 3.4.1) when presenting the Jones (1995b, [180]) semi-endogenous growth model. For the F function, we will also remove all the unnecessary elements for the analysis of the long-run endogenous growth properties of the model from the equation 4.1.1, namely public capital stock (KG_t), fixed cost (FC_Y) and overhead labor (FC_L).

With all these simplifications, the production function for final output can therefore be re-expressed in a first step as

$$Y_t = F(L_{Yt}, x_{it}, A_t) = L_{Yt}^\alpha \cdot \left(\sum_{i=1}^{A_t} x_{it}^\theta \right)^{\frac{1-\alpha}{\theta}} \quad (4.1.3)$$

Then as at the symmetric equilibrium all capital varieties are used in equal quantity, $x_{it} = x_t, \forall i$, we get

$$Y_t = F(L_{Yt}, x_t, A_t) = L_{Yt}^\alpha \cdot A_t^{\frac{1-\alpha}{\theta}} \cdot x_t^{1-\alpha} \quad (4.1.4)$$

As one unit of capital good is produced with one unit of forgone output, the capital stock of the economy (K_t) is the direct sum of the different quantities of capital goods that are used

$$K_t = A_t \cdot x_t \quad (4.1.5)$$

which expression allows us to reintroduce the stock of physical capital in the production function of final output

$$Y_t = F(L_{Yt}, K_t, A_t) = L_{Yt}^\alpha \cdot K_t^{1-\alpha} \cdot A_t^{(1-\alpha) \cdot (1-\theta)}. \quad (4.1.6)$$

We see that this last expression for final output differs from the representation of Romer (1990, [180, 284]) and Jones (1995b, [284]) that we presented in chapter 3, where it was classically

$$Y_t = F(L_{Yt}, K_t, A_t) = (A_t \cdot L_{Yt})^\alpha \cdot K_t^{1-\alpha} \quad (4.1.7)$$

with labor augmenting technical change.

The difference comes from the technology that is assumed for the $F(\cdot)$ function. Romer and Jones use an Ethier (1982, [114]) production function ($Y_t = L_{Yt}^\alpha \cdot \left(\sum_{i=1}^{A_t} x_{it}^{1-\alpha} \right)$) where the marginal productivity of one category of capital goods is independent from the quantities of the other varieties that are used. This is not the case in QUEST and we see from equation 4.1.6 above, that the substitution elasticity between the different categories of capital goods ($\frac{1}{1-\theta}$) must be superior to one so the growth of the number of product varieties positively influences the growth rate of final output in the model.

Turning now to the R&D sector and the ways new ideas are produced in the model, QUEST uses the following adaptation of the initial formulation proposed by Jones⁹ (1995b, *ibid*)

$$\Delta A_t = G(A_{t-1}, A_{t-1}^F, L_{At}) = \delta \cdot A_{t-1}^{F\omega} \cdot A_{t-1}^\phi \cdot L_{At}^\lambda. \quad (4.1.8)$$

With Jones we have the possibility of the fishing-out ($\phi < 1$) and of the stepping on toes ($\lambda < 1$) effects, the novelty being the presence of the variable A_{t-1}^F in the equation, that is introduced to capture the positive influence of international knowledge spillovers through the parameter $\omega > 0$.

To characterize now the long-run growth rate of the production of new ideas, we easily get

$$\frac{\Delta A_t}{A_{t-1}} = \frac{\lambda \cdot n + \omega \cdot n^F}{1 - \phi}. \quad (4.1.9)$$

The main difference to the initial formulation of Jones is that, while the long-run growth rate is positively influenced by the growth rate of the domestic research sector with the term $\lambda \cdot n$, it is now also positively influenced by the growth rate of the research sector (n^F) in foreign countries, through the term $\omega \cdot n^F$. By plugging equation 4.1.9 in equation 4.1.6, and by using the fact that the final

⁹Note that it is assumed in QUEST than only high-skilled labor can be used in the research sector.

output and capital stock grow at the same rate in the long-run, we get finally the expression of the endogenous growth rate of output per capita in QUEST as

$$\frac{\Delta y_t}{y_{t-1}} = \frac{(1 - \alpha) \cdot (1 - \theta)}{\alpha} \cdot \frac{\Delta A_t}{A_{t-1}} = \frac{(1 - \alpha) \cdot (1 - \theta)}{\alpha} \cdot \frac{\lambda \cdot n + \omega \cdot n^F}{1 - \phi} \quad (4.1.10)$$

The long-run growth rate of GDP per capita is therefore a (1) decreasing function of the output elasticity of labor (α) and then is increasing with the capital elasticity ($1 - \alpha$), (2) an decreasing function of the substitution elasticity between the different varieties of capital goods ($\frac{1}{1-\theta}$), (3) a positive function of the sizes of the domestic and foreign research sectors, through the elasticities λ and ω respectively, and finally (4) a positive function of the value of the parameter ϕ . As it was illustrated by Jones (1995a, [179]) in his first 1995 paper focusing on the relative values of the parameters λ and ϕ , there exists a sort of trade_off between them, a value close to one for ϕ implying higher long-run growth and very long transitional dynamics, and conversely for low values of this parameter. For λ , strong values have the effect of increasing the initial impacts of a rise in the R&D effort, and conversely for low values.

4.1.2.2 Calibration of endogenous growth mechanisms

We see that the calibration of the model when using QUEST for the evaluation of EC R&I policies is not easy if one wishes to obtain realistic impacts. These should reflect the relative quality of a country's academic and scientific system, and the ability of firms - measured for example in the present context by the ratio of private R&D expenditure over GDP in different countries - to absorb general scientific and technological knowledge, and to transform it into marketable innovations. The calibration of the QUEST model is described in detail in D'Auria *et al.* (2009, [88]), and table 4.1.1 recaps useful information for the calibration of the endogenous growth rate of GDP per capita in the different countries, given by equation 4.1.10 above.

Table 4.1.1 – Value of the main parameters used to calibrate the effects of innovation in QUEST

	θ	λ	δ	$R\&D_{int}$	L_A	ϕ	g_A
AT	0.91	0.398	0.213	0.034	0.012	0.619	1.15
BE	0.90	0.465	0.309	0.027	0.010	0.555	1.15
BG	0.93	0.645	1.282	0.009	0.004	0.386	1.33
CY	0.88	0.551	1.077	0.006	0.002	0.476	1.33
CZ	0.92	0.496	0.484	0.022	0.010	0.478	1.33
DE	0.91	0.496	0.298	0.032	0.012	0.548	1.15
DK	0.91	0.473	0.255	0.036	0.016	0.548	1.15
EE	0.92	0.482	0.416	0.016	0.007	0.542	1.33
EL	0.90	0.652	1.301	0.010	0.004	0.377	1.15
ES	0.95	0.777	1.745	0.014	0.007	0.257	1.15
FI	0.88	0.441	0.231	0.036	0.015	0.578	1.15
FR	0.91	0.526	0.404	0.026	0.010	0.497	1.15
HR	0.88	0.672	1.598	0.009	0.004	0.361	1.33
HU	0.88	0.595	0.776	0.016	0.006	0.435	1.33
IE	0.92	0.595	0.580	0.017	0.008	0.456	1.15
IT	0.91	0.777	1.752	0.015	0.007	0.257	1.15
LT	0.92	0.582	0.751	0.011	0.006	0.447	1.33
LU	?	0.594	0.659	0.008	0.008	0.432	1.15
LV	0.92	0.738	2.027	0.008	0.005	0.299	1.33
MT	0.88	0.773	2.091	0.009	0.006	0.265	1.33
NL	0.90	0.547	0.431	0.022	0.011	0.477	1.15
PL	0.90	0.542	0.738	0.011	0.004	0.684	1.33
PT	0.92	0.773	1.700	0.015	0.007	0.261	1.15
RO	0.90	0.879	7.658	0.004	0.002	0.164	1.33
SE	0.88	0.335	0.152	0.040	0.014	0.679	1.15
SI	0.90	0.477	0.331	0.028	0.011	0.546	1.33
SK	0.90	0.685	1.439	0.010	0.005	0.349	1.33
UK	0.90	0.495	0.363	0.019	0.010	0.527	1.15

Source: D’Auria *et al.* (2009, [88]) for θ and g_A , and Vargas *et al.* (2019, [321, 322]) for other variables or parameters

The calibration methodology for innovation starts by setting the level of the domestic stock of ideas (A_t) at one. Starting with the value of the parameter λ that represents the congestion elasticity introduced by Jones in the initial model of Romer, it was initially set in QUEST, following D’Auria *et al.* (2009, [88]) to the value of the wage share of R&D labor of the total R&D on spending. But the values of parameter λ are changed in Vargas *et al.* (2019, [321]), without any information on the

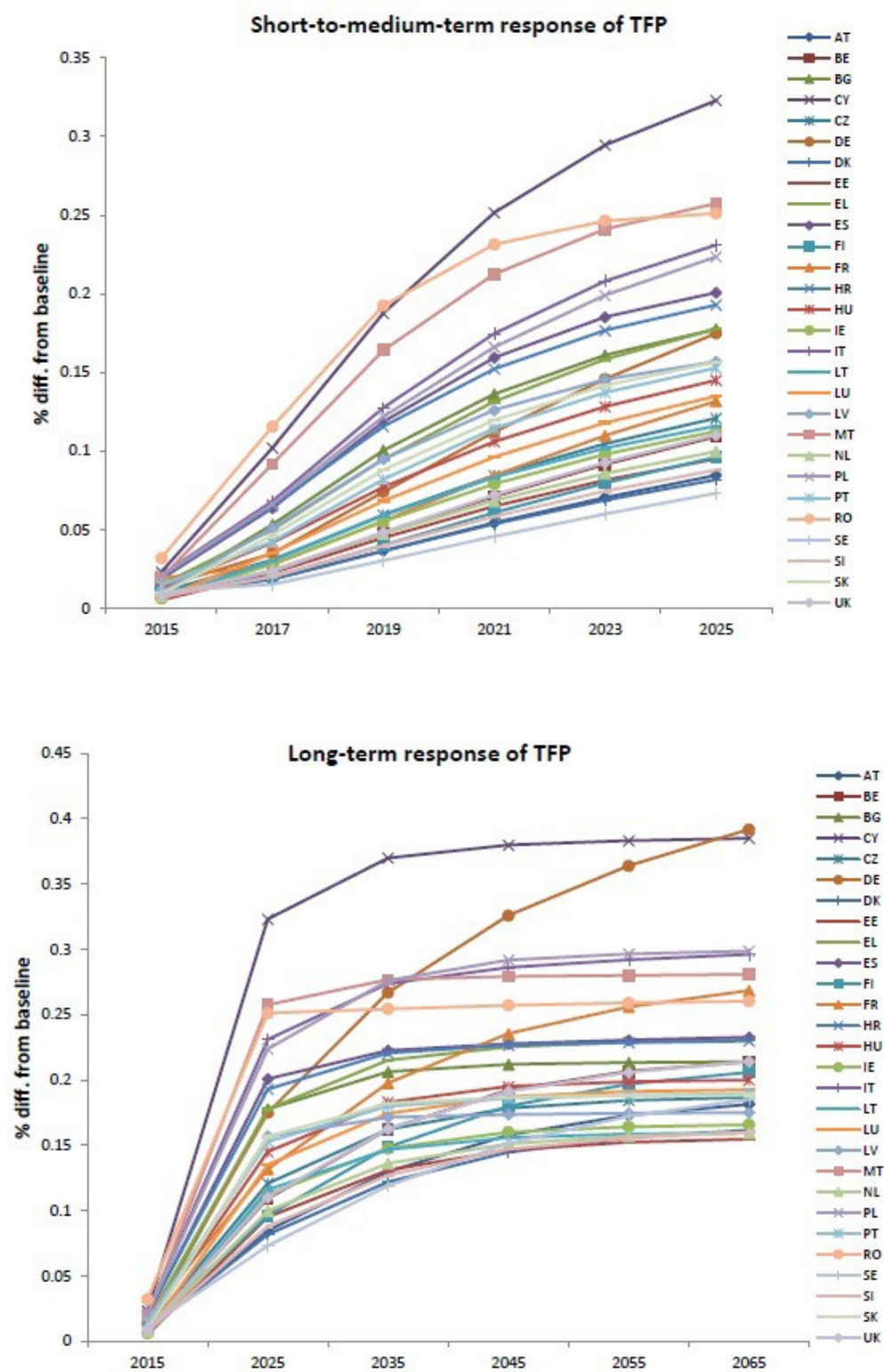
methodology used to calibrate it. These values range from 0.335 in Sweden, up to 0.777 in Spain and Italy, and appear more homogeneous across countries than previously, and center around 0.5. We recall that this parameter λ , strongly affects the short-run impact of R&D on the growth of new ideas. It theoretically reflects the effect of the duplication of R&D efforts by firms and individuals that engage into the R&D race.

We must also underline that the total R&D spending in percentage of GDP (R&Dint) is a measure of the total R&D investment rate of a country, including both R&D investments, by the corporate and the public sectors. Therefore, in the model, the R&D that is financed by the public sector is implicitly assumed to be performed by the private sector.

For the other important parameters of the innovation production function characterizing the long-run growth rate, ϕ and ω , QUEST uses, following D’Auria *et al.* (2009, *ibid*), the long term relationships that were estimated by Bottazzi and Peri (2007, [39]), based on a panel of fifteen OECD countries for the period 1973-1999. The problem is that depending on the regression, their value varies a lot. As the ratio between λ and ω varies less, by imposing the value of this ratio, the value taken by ω can therefore be deduced from the value attributed previously to λ . Then by also fixing the growth rate of new ideas in equation 4.1.9 to 1.33% or 1.15% per quarter¹⁰, and the growth rates of the domestic and foreign R&D sectors (n and n^F), the value of ϕ is deduced. As underlined above, following Jones (1995a, [178]), there exists a kind of trade-off between the values taken by λ and ϕ , and we see from table 4.1.1 that in QUEST they add up, in each country, to a value slightly superior to 1. Once again, we recall the importance of the parameter ϕ that conditions the length of the transitional dynamics of the model when applying a shock to R&D. We already stated in section 3.4.1 that “*For $\phi = 0$ (no spillovers case), the half-life is 35 years for TFP and 62 years for labor productivity. When ϕ rises, the half-life rises considerably and becomes infinite when ϕ approaches 1. It is respectively 69 and 120 years for $\phi = 0.5$, 139 and 242 years for $\phi = 0.75$, and 347 and 674 years for $\phi = 0.90$* ”. The values taken by this parameter in QUEST are contrasted. They range from 0.164 in Romania up to 0.684 in Poland, against values close to 0.1 in Greece and Malta (that had the highest λ) and up to 0.66 in Germany and 0.74 in Netherlands (that had among the lowest λ). With these values of ϕ , the ratio between the country with the longest time transition (Poland) and the one with the lowest (Romania) is quite high. The quarterly time path of the QUEST model, makes the interpretation of

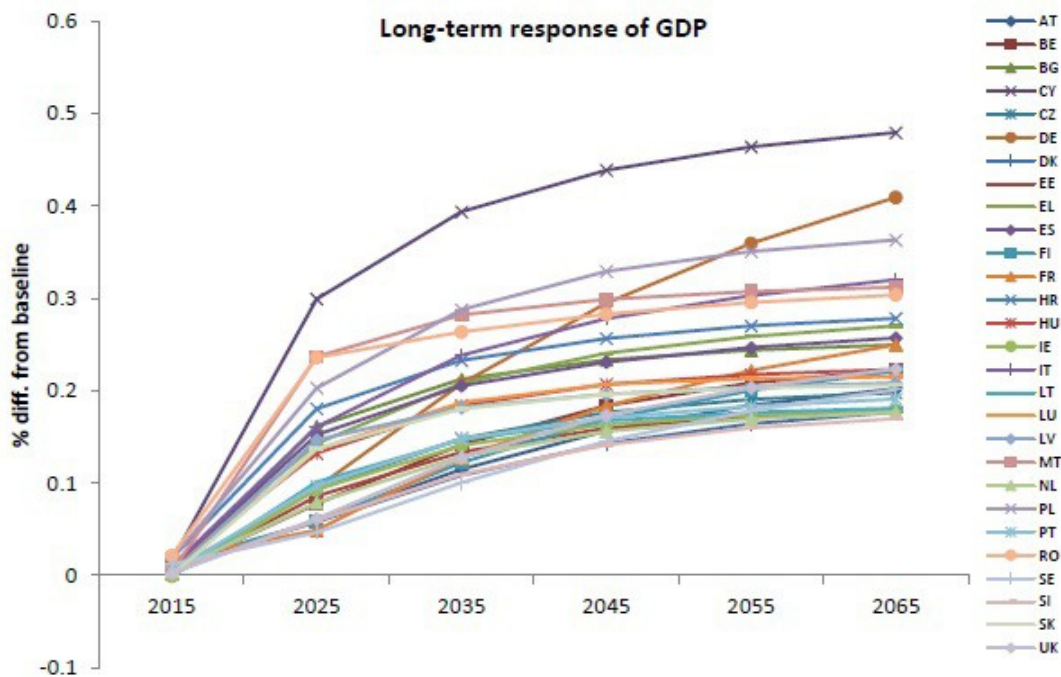
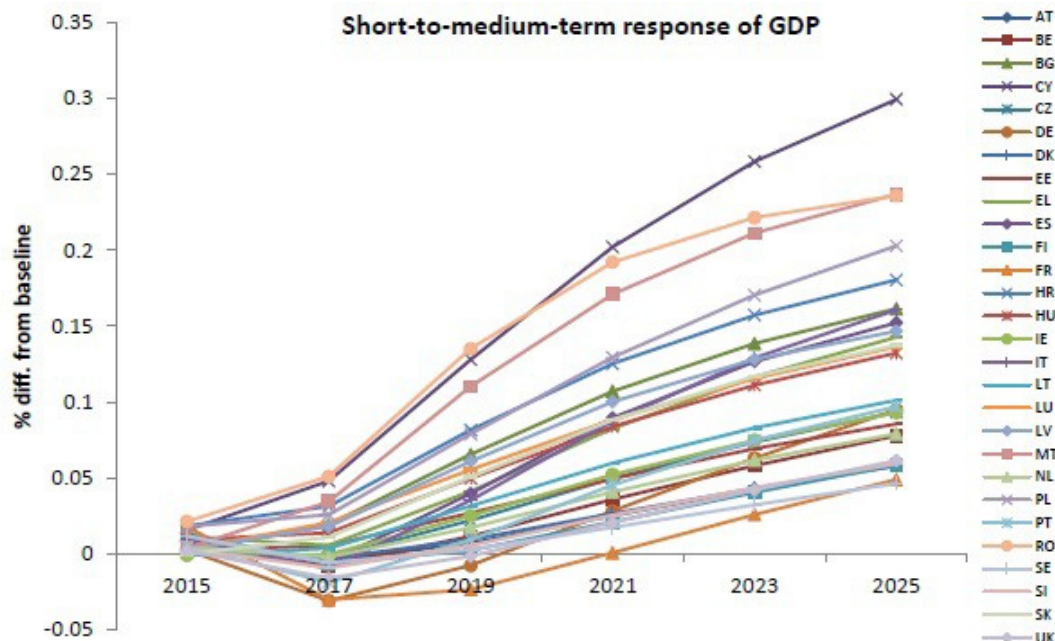
¹⁰The time path of the model is quarterly, which leads to an assumed annual growth rate of innovation of about 5%.

Figure 4.1.1 – Response of TFP to 0.1 GDP point increase of R&D from tax credit



Source: Vargas *et al.* (2019, [321])

Figure 4.1.2 – Response of GDP to 0.1 GDP point increase of R&D from tax credit



Source: Vargas *et al.* (2019, [321])

the parameters more difficult, but from the QUEST analytical simulation results, it appears (see table 4.1.1 for TFP and table 4.1.2 for GDP) that the length of the transition is about 10 years for TFP in Romania and 30 years in Netherlands, that has a value of ϕ close to 0.5. Given the value of ϕ , in the present setting the length of the transition therefore appears to be about 4 times inferior for a same parameter value, as that in the original experiments by Jones (1995a, [178]). For GDP, the length of the transition is as expected, much higher, and no country appears to have fully converged after 50 years.

We can question, in spite of the difficulty to assign values to the different parameters, why D’Auria *et al.* (2009, [88]) assume that in all the countries the innovations grow at the same rate: about 1.25% per quarter, or 5% per year? It is not a problem, under certain conditions, to assume that innovations grow at the same rate in every country for the calibration, but the economic impact of innovations should be differentiated, allowing the countries with the highest scientific and technological base, and the better national systems of innovation, to also have higher positive economic impacts from their innovations. But we can readily see, from equation 4.1.10 that this is not the case in QUEST. From this equation we have:

$$\frac{\Delta y_t}{y_{t-1}} = \frac{(1 - \alpha) \cdot (1 - \theta)}{\alpha} \cdot \frac{\Delta A_t}{A_{t-1}}$$

meaning that in every country the long-run growth rate of GDP per capita is influenced with the elasticity $\frac{(1-\alpha) \cdot (1-\theta)}{\alpha}$ by the growth rate of innovations. Or the coefficient θ that allows us to determine the mark-up of the firms in the intermediate sector is close to 0.9 in every country, and we can attribute to α , that measures the share of wages in value-added, a value close to 0.6. In this setting we obtain as rough estimation for elasticity, a value of about 0.07 meaning that in every country, a 1% increase of new ideas would lead to an identical increase of 0.07% of the growth rate of GDP per capita, and (from equation 4.1.6) of about 0.04% of the growth rate of *TFP*. The values of these two elasticities conform to the average values of the output elasticities to R&D that we have surveyed in chapter 2, and are even conservative. But this empirical literature also says that “*The impact of R&D investment on firms productivity is different at different levels of R&D intensity - the productivity elasticity ranges from -0.02 for low levels of R&D intensity to 0.33 for high levels of R&D intensity, implying that the relationship between R&D expenditures and productivity growth is highly non-linear, and only after a certain critical mass of knowledge is accumulated, is productivity growth significantly positive*” (Kancs and Siliverstovs, 2016, [192], pages 644-645). This result, that is one of key findings of the literature

on R&D and productivity (see again Hall *et al.*, 2009, [155]) at the firm or industry level, is also valid at the country level for QUEST.

A last aspect finally concerns the values that are retained for the productivity of research in the different countries, the parameter δ in equation 4.1.8. We might expect that this productivity parameter would be lower in the less R&D intensive countries, and inversely related to the value of the R&D on GDP ratio in the different countries, allowing a relative equalization of the marginal returns of R&D investments in the first phases of the transitional dynamics of the model. But this is not the case, and as we see on the table 4.1.1, on the contrary, most of the time this parameter is much higher in the countries that invest less in R&D.

4.1.2.3 Some remarks for future improvements

We will end this presentation of QUEST model with a few more general remarks:

- It is difficult to introduce endogenous growth mechanisms that are at the same time theoretically robust, and well-grounded empirically, into the large scale macro models that are used for the evaluation of EC R&I policies. It demands a careful, in-depth analysis of the available empirical and theoretical literature, as described in chapters 2 and 3.
- In the empirical literature, the unavoidable elements are the following: (1) output or TFP elasticities to R&D investments should not be identical in all countries, sectors or regions, and should be inversely proportional to the R&D effort of the different countries, sectors or regions; (2) the social returns to R&D and innovation are at least twice as big as their private returns which means that the externalities occurring between countries, sectors and regions in the macro models, should be described with care; (3) public and private R&D investment have distinct impacts, occurring at different time horizons, and it is important to take into account these differences in the models; (4) external knowledge, from private/public, domestic/foreign origin, can be used only if the countries, sectors or regions have developed a big enough absorptive capacity, as measured notably by the R&D effort (R/Y); (5) there exists many lags between the time of investment in R&D, the innovations, and the economic impacts, and it is important to take them into account to provide a robust evaluation of innovation policies at different points in time; (6) process and product innovations have distinct impacts on economic performance and employment, and it is also crucial to take into account these two categories of innovation.

- From the theoretical literature, we will retain, as an additional element for the macro models (7) the importance that both the growth of knowledge externalities (from the growth of the R&D sector) and the rate of investment in research (the absorptive capacity) have an effect on long-run growth.

Concerning QUEST, and these seven points, our conclusions from the overview of the model are as follows:

(1) the calibration of the economic performance of R&D investments could be improved by allowing output elasticities of R&D and innovations to be inversely related to the R&D intensity of the different countries;

(2) there are elements of social returns, as expected from the inter-temporal knowledge spillovers, and the knowledge externalities that were introduced between countries, but we could not understand how the latter were modeled as they are not described in the available public documentation;

(3) the effects of public and private R&D are not distinguished, and this should be changed;

(4) and (7) a mix of the semi-endogenous and fully endogenous features of the NGT models could ease the calibration of the effects of the R&D in the model, and make them more realistic, as there is no reason to consider that the size alone of the R&D sector is important for long-run growth;

(5) there is no precise information on time lags, but there are temporal effects, such as those arising from the re-allocation of high-skilled labor from production to research in case of a rise in R&D investment, or from the long transitional dynamics implied by the semi-endogenous formulation present in the model;

(6) in the models of Romer (1990, [284]) and Jones (1995b, [180]), on which QUEST based its endogenization of innovation, the only effect of innovation is to increase total factor productivity in the final sector. The representation of innovation in the model is consequently limited to process innovation, and the absence of product innovations should reduce the measured impacts on economic performance and employment, when evaluating the effects of EC R&I policies with the model.

4.1.3 The NEMESIS macro-econometric model

NEMESIS (New Econometric Model for Evaluation by Sectoral Interdependency and Supply) is a model managed by SEURECO, a private company created by researchers from the laboratory ERASME (Équipe de Recherche en Analyse des Systèmes et Modélisations Économiques) of the École Centrale de Paris and the University of Paris I Panthéon-Sorbonne. Originally the model was financed by the

FP6 and FP7 European framework programmes, in collaboration with the University of Maastricht, for innovation and knowledge economics, the laboratory ICCS E3M-LAB of the Polytechnique University of Athens, for energy and environment, and the Federal Planning Bureau, for the accounting framework, the econometric estimations, and software development. Since its first version in 2002, the mechanisms of the model have been regularly enriched by the different European consortia to which the SEURECO/ERASME team belongs to.

NEMESIS like QUEST, is a model for each EU country in interaction with regions in rest of the world, but the two models differ deeply in their modeling approach:

- NEMESIS is an econometric model, from neo-Keynesian inspiration, and the adjustment of prices and quantities in the model include various time lags, reflecting the adaptative structure of the expectations of the economic agents, and the existence of adjustment costs. These features, together with the absence of modeling of the capital market and with the downturn rigidity of wages that is assumed, prevents the model from describing a general equilibrium, even in the long-run.
- In NEMESIS, the macroeconomic growth is the result of the interactions between very heterogeneous production sectors, that provides a complex bottom-up dynamic to the model, that is combined with purely top-down forces, such as the influence of households aggregate final consumption - the model has only one representative category of consumers - and the role of the public sector from the fiscal and budgetary rules, the social contributions and redistribution mechanisms, the provision of the public services, and the public investments and structural policies.

The NEMESIS model is mainly grounded on empirics and econometrics, which allows a great level of detail, in terms of mechanisms and the number of variables the model includes, but this necessarily at the cost of a weakening of its theoretical grounds and of the overall coherence of the model, when compared to QUEST.

Concerning the representation of innovation, the sectorial approach that is followed in NEMESIS nevertheless brings important additions to the variety of analysis that it provides compared to a pure macro model such as QUEST:

- The dynamics of the different economic sectors are very contrasted, and structural changes¹¹ are

¹¹For a very interesting and complete recent survey of the literature on economic growth and structural change, see

pushed by two main forces. There first are demand-driven factors, and notably the assumption of the non-homothetic preferences of the consumers, consistent with the Engle law, with the result that the income share of the products evolves differently as the real disposable income of households increases. The second element, that was notably underlined by Pasinetti (see *e.g.* 1981, [262], and 1993, [263]), is driven by technical progress that occurs through various forces in the different sectors, leading to substitutions between products and the reallocation of employment among the different economic activities. The economic growth process that is described by the model is consequently not an equilibrium “balanced” growth path, and endogenous technical change acts in the model as an acceleration of history, accelerating the decline of the less progressive sectors and speeding-up the growth of the most progressive ones.

- But, as found in the literature, there are also forces in the model, that tend, in the opposite direction, to reduce the extent of the structural transformation of the economy that is created by technical progress. These forces come from what Verspagen and De Loo (1999, [325], P. 218) called the “*equalization effect of R&D spillovers*”, that concern mainly the effects of the rent spillovers embodied in the intermediate and investment goods used by the different sectors. Therefore, while pure knowledge spillovers tend to concentrate in few R&D industrial sectors, the latter diffuse strong productivity spillovers towards the user sectors of the technologies they produce, such as from the ICT sectors toward communication, finance and insurance, from the transport equipment sectors to transport services, or from consumer good technologies to wholesale and retail trade. These equalizing forces also have an international dimension, and for some countries the main channel for technology adoption is the import of high tech equipment.

Finally, another important original feature of the NEMESIS model is that it also represents, besides the effect of process innovation, the distinct impact that product innovations have on employment and economic performance. It is an important point, as the econometric literature generally finds higher output and employment impacts for product than for process innovations. But as we will see, it also complicates the analysis as to the quantitative growth provoked by process innovations, it adds a qualitative component, conceptually at the core of the rent spillovers described above, that necessitates a specific modeling.

After a brief presentation of the general characteristics of the NEMESIS model, we will then detail

Gabardo et al. (2017, [130]) who have guided us toward some of the references we use here.

the main features of the representation of innovation in the model.

4.1.3.1 Overview of the model functioning

NEMESIS distinguishes four categories of economic agents: Households, Financial and Non-Financial Corporations, General Government and the Rest Of the World countries.

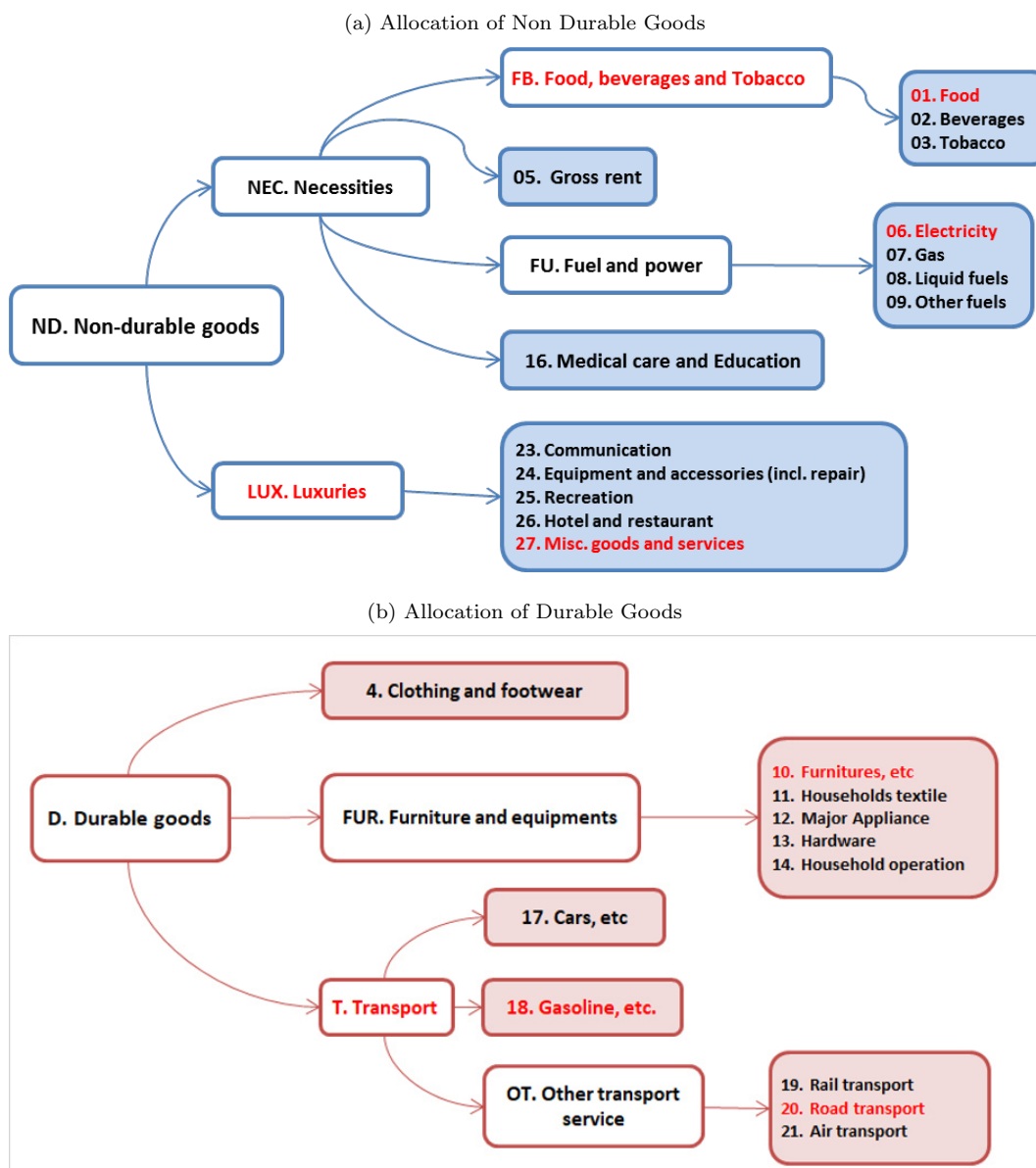
The evolution of the labor supply is supposed as being exogenous in most applications of the model, but “flexion” coefficients of the participation rates of the labor force by age, gender and level of qualification can be introduced. Two types of skills are distinguished, corresponding to two levels of educational attainments: the low-skilled, including ISCED 0 to 4 (Post-secondary non-tertiary education) and the High-skilled (ISCED superior to 4). The wages of each category of labor are determined from an augmented Phillips curve¹². The growth rate of wages is therefore determined, beyond the influence of institutional factors (fixed effects), with adjustments for anticipations of inflation, for labor productivity growth, and for the gap between the current unemployment rate to its assumed structural level. Following Friedman (1968, [128]) and Phelps (1967, [269]), there are therefore inflationary pressures whenever the current level of unemployment is above its structural level, and conversely. Wages are determined at a sectorial level, and differ between sectors because of the differences in the growth rate of productivity and the influence of a structural effect captured by a constant. Labor is finally assumed to be mobile between sectors, but with delays and adjustment costs.

Concerning households, there is one representative consumer. Follow Davidson (1978, [94]), its aggregate consumption expenditure depends on its real disposable income that includes the wages, the revenues of capital, and the social transfers that are received, less the taxes and the social contribution that are paid. The structure of the population is included in the determination of aggregate consumption to capture the modification of consumption patterns caused by an ageing population. The unemployment rate is used also as a proxy for measuring the degree of uncertainty on expected revenues in the short run, with an influence of the real interest rate as well. The specification used retains an error correction modeling. Savings are determined simply as the difference between the levels of real disposable income and of final consumption; there is no forward-looking Ramsey-type optimization behavior. Final consumption is further decomposed between 27 different consumption functions, from an adaptation of the Almost Ideal Demand System (AIDS) proposed by Deaton and

¹²As a consequence, wage bargaining is based on the growth rate of the wage rate, and not on the level of the reservation wage, as in the WS/PS approach.

Muelbauer (1980, [96]). The allocation scheme distinguishes between the influence of relative prices, of income and of demographic changes. Their effects are different for each consumption category that is displayed on figure 4.1.3.

Figure 4.1.3 – Allocation of the aggregate consumption



In red the consumption functions ensuring the accounting identities

On the firms side, the final output in the different production sectors (see the list of sectors in table 4.1.2) is obtained from five level nested CES production functions (figure 4.1.4). In each sector,

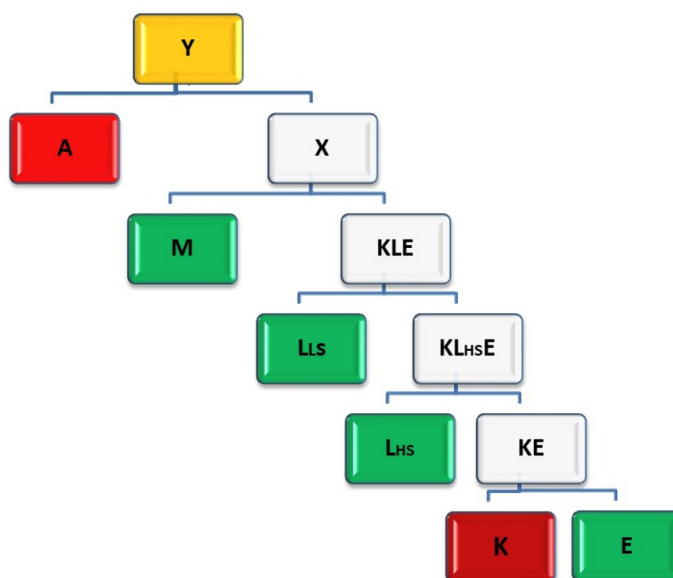
Chapter 4. The endogenization of innovation on R&D

the production (in yellow) results from the combination of four variable inputs (in green) and two quasi-fixed inputs (in red). The variable inputs are Materials (M), Energy (E), Low-Skilled Labor (L_L) (ISCED 1 to 4) and High-Skilled Labor (L_H) (ISCED 5 and 8). The quasi-fixed inputs are physical capital stock (K) and innovations (A). The other inputs (in white) are compound inputs - or “*intermediate outputs*” - corresponding to the different levels of the nested CES function. In this current version of production nesting, innovations therefore intervene on the first level, meaning that they proportionally influence the use of ordinary production factors, represented by the variable $X = KLEM$ that groups together the physical capital stock, the two categories of labor, energy and materials. The impact of innovation on the production function for (X) is consequently Hick’s neutral as it does not affect the balance between production factors. The innovation function for producing A , and the way innovations influence demand and output growth at sectorial level, is detailed below.

Table 4.1.2 – List of sectors modeled in the NEMESIS model

Number	Sector	Number	Sector
01	Agriculture, etc.	16	Food, drink and tobacco
02	Other extraction	17	Textile, etc.
03	Oil & Gas extraction	18	Paper & printing products
04	Gas distribution	19	Rubber & plastic
05	Refined oil, etc.	20	Other manufactures
06	Electricity	21	Construction
07	Water supply	22	Distribution
08	Ferrous and non-ferrous metals	23	Lodging and Catering
09	Non metallic mineral products	24	Inland Transport
10	Chemicals	25	Sea & Air Transport
11	Metal products	26	Other transport services
12	Agricultural & Industrial machines	27	Communication
13	Office machines	28	Bank, Finance, Insurance & real estate
14	Electrical goods	29	Other market services
15	Transport equipment	30	Non-market services

Figure 4.1.4 – The CES production functions



On the accounting framework and the way the economic agents interact in the model, the input/output and the convert matrices of the model play an important role to ensure the concordance between all the demands formulated by the various agents (firms, consumers, government, exports), and the demand addressed to the producers, domestic and foreign. They transform and balance the sum of factor demands, consumption by product, household investments, government expenditure and foreign demand, into equivalent addressed demands by product. Institutional sector accounts are established in NEMESIS on the basis of the EUROSTAT database. The various institutional sectors that are represented are the General Government (GG), Households and Non-Profit Institutions Serving Households (HNPIH)¹³, Financial Corporations (FC), Non-Financial Corporations (NFC), all of which are of course linked to the sectorial nomenclature of the model. These agents accounts are described from the production account up to the Acquisition of non financial assets account (*i.e.* up to the b9 Net lending (+) /net borrowing (-)), and allows for, concerning households, a very accurate representation of the formation of their revenue. Similarly the great detail of the taxation system (see table 4.1.3) permits the precise calculation of the general government budget surplus, and the possibility to apply and analyze the impacts of diverse various policies.

¹³Since the split of households and NPISH's was not possible for most countries, it had been decided not to separate them until data is available.

Table 4.1.3 – Principal taxes and subsidies

D2	Taxes on production and imports
	Including value added taxes; taxes and duties on imports excluding VAT; Taxes on products except VAT and import taxes; Excises duties and consumption taxes; Other taxes on production
D3	Subsidies
	Including Subsidies on products and Other subsidies on production
D5	Current taxes on income, wealth, etc.
	Including Taxes on income and Other current taxes
D61	Social contributions
	Including social contributions and Imputed social contributions
D9	Capital Transfers
	Including Capital taxes and Investments grants

Lastly, for external trade, NEMESIS processes by pool, Each modeled country exports to (and imports from) two pools that group together either European Union countries or extra-EU countries. Therefore, there is no description of the precise country of origin or of the destination within these pools. Trade flows are determined from the relative price adjusted from the quality of the products from different origins, and from activity variables such as world demand for extra-EU trade, and domestic demand for imports.

4.1.3.2 Modeling of innovation

Let's now consider the representation of innovation in NEMESIS. The parallel with the NGT models in chapter 3, and the analysis in terms of the F and G functions is less straightforward than for QUEST, given the sectorial structure of the model. We furthermore have an additional element with the introduction of product innovation into the framework.

Therefore, the methodology for the introduction of endogenous innovation in the model first consists in translating these F and G functions at a sectorial level. We first have, for the F function, following

the first level of the CES nesting for production in the model (see figure 4.1.4):

$$Y_{it} = F(A, X) = C_i \cdot \left[\delta_{A_i}^{1+\rho_{Y_i}} \cdot A_{it-1}^{-\rho_{Y_i}} + \delta_X^{1+\rho_{Y_i}} \cdot X_{it}^{-\rho_{Y_i}} \right]^{-\frac{1}{\rho_{Y_i}}} \quad (4.1.11)$$

with: C , a scale parameter, δ_A the share parameter for A theoretically representing the cost of innovation in the total cost of producing Y , δ_X , similarly, the share parameter for X with by definition $\delta_X = 1 - \delta_A$, and ρ_y , the parameter defining the partial substitution elasticity between innovation services and X as $\sigma_Y = \frac{1}{1+\rho_Y}$.

We have for the function G , the production function for innovations in a sector i :

$$A_{it} = G(KNOW, \frac{R\&D}{Y}) = SC_{A_i} \cdot KNOW_{it}^{\lambda_i \cdot \frac{R\&D_{it}}{Y_{it}}}, \quad (4.1.12)$$

with SC_A , a scale parameter. Innovations are assumed to be a positive function of the sector's (and country) specific knowledge stock, $KNOW_t$, and of its knowledge absorption capability, that is measured by $\lambda \cdot \frac{R\&D}{Y}$, with $\frac{R\&D}{Y}$ the R&D intensity of the sector, and $\lambda > 0$, a productivity parameter.

Three remarks are important at this stage:

Firstly, we see from the function F that innovations “enter” the production function. The presence of A in F represents the impact of process innovations that the firm implements from using its profit optimization program. In NEMESIS, we suppose that the function F has constant returns to scale on A and X because (1) innovations are supposed to be produced in-house, and (2) that as there is only one representative firm per sector, it would look odd to suppose that it faces increasing returns to scale.

Secondly, the function F is assumed *CES*, but there is no reason to consider that innovations are not perfectly substitutable with the “ordinary” production factors regrouped under the variable X . In practice, we use only the case where $\sigma_Y = 1$, which means we can rewrite the function F above as

$$Y_{it} = F(A, X) = C_i \cdot A_{it-1}^{\delta_{A_i}} \cdot X_{it}^{1-\delta_{A_i}} \quad (4.1.13)$$

by also assuming, from the calibration procedure, that $\delta_X = 1 - \delta_A$, and that the returns to scale on F are constant.

Thirdly, assuming that the R&D intensity is constant in the long-run throughout the reference

model scenario, as we usually do, taking the function G in growth rates we get

$$\frac{\Delta A_{it}}{A_{it-1}} = \lambda_i \cdot \frac{R\&D_{it}}{Y_{it}} \cdot \frac{\Delta KNOW_{it}}{KNOW_{it-1}}. \quad (4.1.14)$$

The growth rate of innovations at sectorial level in the long-run, is therefore proportional to the growth rate of knowledge externalities. The representative firm can therefore increase the growth rate of its innovation by investing an higher amount of its resources in R&D. But we see that if the firm keeps its R&D effort ($\frac{R\&D}{Y}$) constant, as knowledge externalities grow at a positive rate in time, it allows innovations to grow proportionally. The true source of increasing returns in the model is consequently, like in the NGT models (chapter 3), the inter-temporal growth rate of knowledge externalities. We must also say that this representation of innovation in NEMESIS, was grounded on the findings in the literature on R&D and productivity we surveyed in chapter 2. And it allows us to take into account two main findings from this literature: (1) the central role that pure knowledge spillovers play in the process of growth, and (2) and the necessity to have sufficient absorptive capacity of these externalities ($\frac{R\&D}{Y}$), to be able to transform them into marketable innovations. These two elements also are at the core of the most elaborate second generation of fully endogenous growth models.

Knowledge spillovers, are modeled as weighted sums of the R&D stocks¹⁴ belonging to all sectors and countries, from methodologies measuring these externalities at the same time in the intra-sectorial and in the international dimensions.

The knowledge variable of the sector i in country c , $KNOW_{cit}$, is defined by the sum of R&D capital stocks $SR_{p,s,t-\Delta}$ from all countries/sectors (p, s) , weighted by a coefficient of diffusion $\Psi_{p,s \rightarrow c,i}$ reflecting the relative propensity of knowledge from a sector s in country p to be useful to innovate in sector i in country c . We also consider that R&D investments start producing knowledge after a delay Δ fixed at two years.

$$KNOW_{c,i,t} = \sum_{p,s} \Psi_{p,s \rightarrow c,i} \times SR_{p,s,t-\Delta} \quad (4.1.15)$$

Public investments in R&D ($PIRD$) are taken into account and their externalities allocated to the different sectors according to a grand fathering distribution¹⁵, and generate knowledge externalities

¹⁴The depreciation rate that is used for R&D is 15%, as usual in the literature on R&D.

¹⁵They are proportional to the share of each sector in the overall business R&D expenditure.

after a longer time lag than private R&D (2 years more) so that $SR_{p,s,t} = (1 - \delta_{RD}) SR_{p,s,t-2} + IRD_{p,s,t} \propto_{p,s} PIRD_{p,t-4}$.

Diffusion parameters are calibrated using matrices based on patent citations between sectors and countries¹⁶. These matrices combine the citations between patents allocated by technology class and country using OECD concordance table (Johnston, 2002, [176]) in order to allocate these citations between sectors¹⁷.

We can notice that private and public R&D expenditures have an asymmetric impact on the production of innovations: private R&D investments increase knowledge and increase the capacity of the firms to transform knowledge into innovations, while public R&D investments only add to the knowledge stocks in the sectors, but with a longer delay than for private R&D investments. We also see from equation 4.1.13 that innovations are themselves productive after another delay of one year.

The last important feature of innovation mechanisms is the presence of product innovations, and two effects of innovations are distinguished in NEMESIS:

- From equation 4.1.13, they act as “*process innovations*”, that decrease ex-ante the use of X_{it} , the compound input for ordinary production factors, per unit of output, Y_{it} , with an elasticity α_i ;
- Innovations also increase, ex-ante, the quality of products, with an elasticity α'_i , but without decreasing the use of X_{it} per unit of output, Y_{it} .

At each date t , the representative firm of the sector i in country c , chooses the amount of innovation that maximizes its expected inter-temporal profit flows, Π_{cit} , by solving the following program:

$$\begin{aligned} \underset{\{A_{it}\}}{MAX} \Pi_{it} &= E_t \sum_{s=t}^{\infty} \left\{ \left(\frac{1}{1+a} \right)^{s-t} \cdot [(P_{y_{is}} \cdot Y_{is} \right. \\ &\quad \left. - TC_{X_{is}}^{ST}(\cdot) - P_{A_{is}} \cdot A_{is}] \cdot (1 - \tau_{\pi}) \right\} \end{aligned}$$

where E_t is the expectation function, a the actualization rate, $P_{y_{is}}$, the price of output, $P_{A_{is}}$ the price of innovation services, τ_{π} the corporate tax rate and where $TC_{X_{is}}^{ST}(\cdot)$ is the short term total cost of using the bundle of ordinary production factors X_{is} - that is to say, for A fixed to its current level, and not already optimized.

As firms' customers are assumed to have a “*taste for quality*”, their demand increases whenever the

¹⁶These matrices were developed by Meijers and Verspagen (2010 [?]) in the framework of the DEMETER project (see also Belderbos and Mohnen, 2013 [26]).

¹⁷We describe additional elements on the construction of these matrices in the chapter 4.

quality adjusted price of products, $\frac{P_{y_{is}}}{Q_{is}}$, decreases, with $Q_{is} = A_{is-1}^{\alpha'_i}$ ($\alpha'_i > 0$), the quality index of output, and $\varepsilon_{pi} = \frac{d \ln(P_{y_{is}} \cdot Y_{cs})}{d \ln(Q_{is})} > 0$, the elasticity of sales with respect to quality. This is shown in the following demand function¹⁸:

$$Y_{is} = Y_0 \cdot \left[\frac{\left(\frac{P_{Y_{is}}}{Q_{Y_{is}}} \right)}{\left(\frac{\bar{P}_{Y_{is}}}{\bar{Q}_{Y_{is}}} \right)} \right]^{-\varepsilon_{pi}} \cdot D_{is}^{\varepsilon_d} \quad (4.1.16)$$

where $\bar{P}_{Y_{is}}$ represents the average price of competitors, \bar{Q}_{is} is a measure of the average quality of the of competitors products, $-\varepsilon_{pi} < 0$, is the elasticity of demand to the relative prices adjusted for quality, D_{is} , is the aggregated demand addressed to national producers, domestic and external, and Y_0 is a scale parameter. Furthermore, if ε_d , that represents the elasticity of firm's output to aggregate demand, equals 1, the market share of the sector remains constant, as long as its relative competitiveness, measured by the ratio $\frac{\left(\frac{P_{Y_{is}}}{Q_{Y_{is}}} \right)}{\left(\frac{\bar{P}_{Y_{is}}}{\bar{Q}_{Y_{is}}} \right)}$, also stays constant.

The particularity of this profit maximization problem is that we have a decision variable, the innovation services, A_{it} , that plays two roles: It reduces the use of ordinary production factors and then their user cost, $\frac{\partial TC_{X_{is}^{ST}}(\cdot)}{\partial A_{is}} < 0$, and it allows the firm to increase its turnover (as $\frac{\partial P_{Y_{is}} \cdot Y_{is}}{\partial A_{is}} > 0$), through the taste for quality of customers.

Now to express the first order optimality conditions, for $s = t$, we have:

$$\frac{\partial \Pi_T}{\partial A_{it}} = E_t \left[\frac{\partial (P_{Y_{it+1}} \cdot Y_{it+1})}{\partial A_{it}} - \frac{\partial TC_{X_{it+1}^{ST}}(\cdot)}{\partial A_{it}} \right] - w_{Ait} = 0 \quad (4.1.17)$$

where the user cost of innovations, w_{Ait} , is equal to:

$$w_{Ait} = P_{Ait} \cdot (1 + a_c). \quad (4.1.18)$$

As innovations have two distinct effects, equation 4.1.17 cannot be solved analytically for A_{it} .

The solution that is used in NEMESIS is to redefine the user cost of innovations as:

¹⁸The actual sectorial demand functions of NEMESIS are additive functions resuming the different uses of a product, where imports are subtracted to obtain the demand addressed to domestic firms. We therefore have for a good i , $Y_{it} = ADDINTCONS_{it} + ADDCONS_{it} + ADDINV_{it} + ADDGOV_{it} + DSTOCK_{it} + EXPTOT_{it} - IMPTOT_{it}$, where the total demand addressed to the sector (Y_{it}) is equal to the use of sector i output for respectively, intermediate consumption, households final consumption, investment, public consumption, stock variation and exports less imports.

$$\tilde{w}_{A_{it}} = w_{A_{it}} - E_t \left(\frac{\partial (P_{Y_{it+1}} \cdot Y_{it+1})}{\partial A_{it}} \right), \quad (4.1.19)$$

where $E_t \left(\frac{\partial (P_{Y_{it+1}} \cdot Y_{it+1})}{\partial A_{it}} \right) = E_t \left(\varepsilon_{pi} \cdot \alpha'_i \cdot \frac{Y_{it+1}}{A_{it}} \cdot P_{Y_{it+1}} \right)$ is the ex-ante marginal impact on expected sales of investing in innovation.

We then proxy in NEMESIS $\tilde{w}_{A_{it}}$ by $(1 - sp_i) \cdot w_{A_{it}}$, with $sp_i = \frac{E_t \left(\frac{\partial (P_{Y_{it+1}} \cdot Y_{it+1})}{\partial A_{it}} \right)}{E_t \left(\frac{\partial (P_{Y_{it+1}} \cdot Y_{it+1})}{\partial A_{it}} \right) - E_t \left(\frac{\partial (TC_{it+1}^T)}{\partial A_{it}} \right)}$ defined as the “share” of product innovations in the total ex-ante expected marginal revenues by firms from their innovations, that is fixed as 33% in the model (for every sector and country).

With this “modified” expression for the user cost of innovations, we can now easily solve equation 4.1.17 for A_{it} , which results in, after calculation:

$$A_{cit}^* = E_t \left\{ \delta_A \cdot \left(\frac{\tilde{w}_{Acit}}{P_{Y_{cit+1}}} \right)^{-1} \cdot Y_{cit+1} \right\} \quad (4.1.20)$$

where expectations on the growth rate of forward looking variables are assumed as adaptive.

The optimal demand for innovation is therefore simply a positive function of expected demand (or output) and a negative function of the ratio between the innovation services “modified” user cost and the production price, with an elasticity -1 .

The optimal R&D demand is therefore obtained by inverting equation 4.1.12 for $A_{it} = A_{it}^*$:

$$R\&D_{it}^* = \left[\frac{\ln(A_{it}^*) - \ln(SC_{Ai})}{\ln(KNOW_{it})} \right] \cdot \frac{Y_{it}}{\lambda_i}. \quad (4.1.21)$$

We see from equation 5.3.17 that the desired intensity of R&D, $\frac{R\&D_{it}^*}{Y_{it}}$, will increase whenever the desired level of innovation increases, and decrease whenever the growth rate of knowledge externalities increases. The reason for this later property is that knowledge increases the productivity of R&D: if knowledge grows, less R&D is needed for producing a given level of innovation. The desired intensity of R&D will also be negatively influenced by its user costs. We must underline that this last equation, because of its semi-log form, is very difficult to calibrate and various normalizations are used in order to control the force of the effects just described.

4.1.3.3 Endogenous growth properties in the model

In this section we more closely analyze the endogenous growth properties resulting from the innovation mechanisms of NEMESIS. We must underline that, due to composition effects, this analysis is only

possible at a sectorial level, and the endogenous growth properties in the model, at macro level, can be only studied by simulating the model.

Let's start by expressing the long term growth rate of sectorial output in NEMESIS. By first differentiating the equation for sectorial output (equation 4.1.13) with respect to time by using natural logarithms, we obtain:

$$\frac{d \ln(Y_{it})}{dt} = \varepsilon_{A_{it}}^{Y_{it}} \cdot \frac{d \ln(A_{it})}{dt} + \varepsilon_{X_{it}}^{Y_{it}} \cdot \frac{d \ln(X_{it})}{dt} \quad (4.1.22)$$

with:

$$\varepsilon_{A_{it}}^{Y_{it}} = \frac{\partial \ln(Y_{it})}{\partial \ln(A_{it})} = \delta_{Ai} \quad (4.1.23)$$

the elasticity of sectorial output with respect to innovations (A), and:

$$\varepsilon_X^{Y_{it}} = \frac{\partial \ln(Y_{it})}{\partial \ln(X_{it})} = 1 - \delta_{Ai} \quad (4.1.24)$$

the elasticity of sectorial output with respect to the bundle of traditional production inputs (X).

The long term growth of sectorial output therefore decomposes into two components:

1. An “*endogenous*” one, driven by the growth of innovation services:

$$\frac{d \ln(Y_{it}^A)}{dt} = \varepsilon_{A_{it}}^{Y_{it}} \cdot \frac{d \ln(A_{it})}{dt} \quad (4.1.25)$$

2. and an “*exogenous*” one, driven by the growth of traditional production factors:

$$\frac{d \ln(Y_{it}^E)}{dt} = \varepsilon_{X_{it}}^{Y_{it}} \cdot \frac{d \ln(X_{it})}{dt} \quad (4.1.26)$$

so we have:

$$\frac{d \ln(Y_{it})}{dt} = \frac{d \ln(Y_{it}^A)}{dt} + \frac{d \ln(Y_{it}^E)}{dt} \quad (4.1.27)$$

We see from equation (5.3.26) that the “*endogenous*” growth rate of sectorial output can be assimilated with a “*pure*” TFP effect, as the empirical studies generally do. We therefore have:

$$\frac{d \ln(Y_{it}^A)}{dt} = \frac{d \ln(TFP_{it})}{dt} = \frac{d \ln(Y_{it})}{dt} - \frac{d \ln(Y_{it}^E)}{dt} \quad (4.1.28)$$

or equivalently:

$$\frac{d\ln(TFP_{it})}{dt} = \frac{d\ln(Y_{it})}{dt} - \varepsilon_{X_{it}}^{Y_{it}} \cdot \frac{d\ln(X_{it})}{dt} \quad (4.1.29)$$

Using this first interpretation, the problem of empirical studies is to measure to what extent the growth of TFP, that is to say the gap between the growth of output and the growth of traditional production factors, can be explained by investments in innovation inputs, such as R&D and related knowledge externalities.

In practice, the TFP indexes that can be computed from economic data, summarize many different effects, and the joint influence of many different mechanisms, as we will now show.

We can, using our modeling approach, first define the “TFP effect” as *minus* the elasticity of the demand for production inputs with respect to innovation, with Y_{cit} kept constant:

$$\alpha_{it} = -\frac{\partial \ln(X_{it})}{\partial \ln(A_{it})} = \frac{\varepsilon_A^{Y_{it}}}{\varepsilon_X^{Y_{it}}} \quad (4.1.30)$$

We see that this “TFP effect” is different from the definition given by equation 5.3.28 and must be interpreted this time as a measure of the deformation of the set of production possibilities provoked by the growth of innovation services in time, for a fixed level of output.

The second effect of innovation in NEMESIS is linked to the increase in the demand addressed to the firms provoked by the gradual improvement in the characteristics of their products (from equation E23 in table 5.3.2). This “Quality effect” is defined as:

$$\frac{d\ln(Q_{it})}{dt} = \alpha'_{it} \cdot \frac{d\ln(A_{it})}{dt} \quad (4.1.31)$$

In each sector, the *quality* of output is supposed to evolve in time proportionally (with a coefficient m_i) to the “TFP effect” so we have:

$$\alpha'_{it} = m_i \cdot \alpha_{it} \quad (4.1.32)$$

In NEMESIS these two distinct innovations (or *innovation effects*) act on the sectorial output of firms through the price elasticity of demand, $\varepsilon_{it}^D < 0$:

1. Process innovation will reduce the unit cost of the firms with an elasticity α_{it} and, as firm will

by assumption proportionally reduce their price, his will increase demand with the elasticity:
 $-\varepsilon_{it}^D \cdot \alpha_{it}$.

2. Product innovation will increase demand with the elasticity: $-\varepsilon_{it}^D \cdot \alpha'_{it}$

As at equilibrium, the level of output equates the level of demand, the growth rate of output provoked by the growth of innovations, that-is-to-say, the “*endogenous*” growth rate of output, $\frac{d \ln(Y_{it}^A)}{dt}$, will then be equal to:

$$\frac{d \ln(Y_{it}^A)}{dt} = \left(-\varepsilon_{it}^D \cdot \alpha_{it} - \varepsilon_{it}^D \cdot \alpha'_{it} \right) \cdot \frac{d \ln(A_{it})}{dt} = -\varepsilon_{it}^D \cdot (1 + m_{it}) \cdot \alpha_{it} \cdot \frac{d \ln(A_{it})}{dt} \quad (4.1.33)$$

This “*endogenous*” growth rate of sectorial output does not simply measure a pure TFP effect, as in equation 5.3.29, and it is, on the contrary, the resultant of three combined effects:

1. A TFP effect through the elasticity α_{it} ;
2. A quality effect through the elasticity $\alpha'_{it} = m_i \cdot \alpha_{it}$;
3. And a demand effect through the elasticity ε_{it}^D .

Then finally, by plugging equation 4.1.14 into equation 4.1.33 we get:

$$\frac{d \ln(Y_{it}^A)}{dt} = -\varepsilon_{it}^D \cdot (1 + m_{it}) \cdot \alpha_{it} \cdot \lambda_i \cdot \frac{R\&D_{it}}{Y_{it}} \cdot \frac{\Delta KNOW_{it}}{KNOW_{it-1}}. \quad (4.1.34)$$

A few general comments on the implications of this last equation on the properties of the endogenous growth (of output) in NEMESIS may be useful at this stage:

- Firstly, there is no endogenous growth at a sectorial or macro level in NEMESIS without growth in knowledge externalities. From a theoretical perspective, this property re-links the modeling of innovation in NEMESIS to the semi-endogenous growth literature where the ultimate source of growth is the size of the R&D sector (here at world level) and of knowledge externalities that expand with the growth of population. The consequence is that the endogenous growth rate in NEMESIS is strongly dependent on the assumptions made on the growth of knowledge externalities in the reference scenario of the model. We generally assume in the reference scenario, that investment rates in R&D stay constant from the medium (say 10 years) to long term in European countries, but also in regions in the rest of the world .

- Secondly, the approach used in NEMESIS conforms to the *Schumpeterian* or *Fully endogenous II* approach initiated by Aghion and Howitt (1998 [8]), Dinopoulos and Thompson (1998 [101]) and Peretto (1998 [266]): the long term endogenous growth rate is an increasing function of the investment rate in R&D, that can be influenced by policy instruments.
- Thirdly, from the two first points, the way policies aiming to raise innovation input intensities, such as subsidies, will act on the long term endogenous growth rate, decomposes into two effects:
 1. an increase of the ability of firms to exploit existing knowledge (*intensity effect*)
 2. and the creation of new knowledge that increases the intrinsic productivity of innovation inputs (*knowledge effect*) .

These two effects can play very different roles depending on the sector or the country under consideration.

4.1.3.4 Implications of product innovation for the measurement of growth

A last important feature, on the supply side of the model, is pricing behavior and the dichotomy between “*actual*” prices and “*perceived*” prices, that the “*quality effects*” resulting from product innovation provoke.

To start with the production prices, we assume in NEMESIS that the firm applies a constant mark-up over its total operational unit cost, so we have:

$$P_{Yit} = (1 + TM_i) \cdot \frac{\sum_j w_{jit} \cdot j_{it}}{Y_i}, \quad j = K, L_L, L_H, E, M \quad (4.1.35)$$

where P_{Yit} is the production price and TM_i the mark-up rate, that differs between countries and sectors.

For a given firm or sector i , the market price, i.e. the price at which the firm will sell its product, will also reflect the influence of taxes, notably VAT, such as:

$$P_{Yit}^M = P_{Yit} \cdot (1 + tax_{it}) \quad (4.1.36)$$

with P_{Yit}^M the market price, where we assume here, for simplicity, that all the taxes (tax_{it}) are *ad valorem*.

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These production and market prices, are those used to calculate the GDP in value, and all its counterparts: final private and public consumption, investment, imports and exports.

The difficulty is now that, in the model, customers of the firms, whether households and government for final consumption, or firms, households and government for investments, or foreign countries for exports, all use quality adjusted prices (P_{Yit}^Q) for their purchasing decisions:

$$P_{Yit}^Q = \frac{P_{Yit}^M}{Q_{it}} \quad (4.1.37)$$

that we call “*perceived*” prices.

So for the illustrative demand function given by equation 4.1.16 above, the decisions to use goods and services produced domestically or imported, and the substitutions between the different production and consumption goods, will all be made by comparing the quality adjusted prices of the different products.

So the model can have two different measures of GDP at a constant price.

The first, the GDP in ordinary units, GDP_t , corresponds to the one usually calculated by national accounting systems, including the correction for the improvement in quality for certain products, such as those currently applied for ICT.

The second is the GDP “*adjusted*” for quality, includes the additional variation in quality of the different goods and services that is calculated by the model, when increasing innovation. If we call Q_{GDPt} this quality index of the GDP, we therefore have , for the GDP adjusted from quality (GDP_t^Q):

$$GDP_t^Q = GDP_t \cdot Q_{GDPt}. \quad (4.1.38)$$

Note that the GDP “*adjusted for quality*” will be always superior to the GDP calculated in “*ordinary units*” in a scenario increasing innovation and product quality¹⁹

For the GDP price, we can, like for production price, distinguish between the “*ordinary*” price, P_{GDPt} , and the GDP price “*adjusted for quality*”, $P_{GDPt}^Q = \frac{P_{GDPt}}{Q_{GDPt}}$.

This “quality adjusted” price will therefore always be inferior to the “*ordinary*” price in a scenario where product innovation increases.

¹⁹Note that, as we described in chapter 2, national accounting systems also apply corrections for quality improvement, such as for ICT. These corrections are implicitly included in the reference scenario NEMESIS, when we generally assume that the growth of innovations is constant in forward-looking scenarios.

Note also that the GDP in value, $GDPV_t$, is identical, whatever the definitions retained for the GDP and for its price:

$$GDPV_t = P_{GDP_t} \cdot GDP_t \equiv P_{GDP_t}^Q \cdot GDP_t^Q. \quad (4.1.39)$$

The problem now is: What definition should we retain for the GDP, the GDP price and all the accounting variables calculated by the model, when presenting the simulation results?

Our practice is to present all the results in “ordinary” units, as it is the way that the most adequately reflects the accounting rules currently in use in the European accounting system. Thus, we certainly understate, when assessing innovation policies using NEMESIS and presenting the results, the impacts on the GDP and sectorial activity. For employment and environmental variables, that are expressed in physical units, this measurement problem does not exist.

4.1.3.5 Some indications on the calibration of innovation

This last section provides some information on the calibration of the innovation mechanisms of NEMESIS. It is only a brief presentation, and additional elements, with analytical tests, are provided later in chapter 5. We just want to underline that this calibration concords with the main findings in the econometric literature on R&D surveyed in chapter 2, and with the 7 crucial elements underlined at the end of the presentation of the model QUEST. This is the case, as the modeling of R&D and innovation in NEMESIS was specifically designed to stay in line with the key findings in the literature. Therefore, the impacts (on the economic performance of a sector) of investing in R&D in NEMESIS is a positive non-linear relationship between the investment rate in R&D (in % of production or value-added), close to the findings of Kancs and Siliverstovs (2016, [192]). This effect is easy to control, as it is calibrated through the value that is imposed for the parameter δ_A , that measures the output elasticity of innovation in the production function of final output, and it should also reflect the share of the cost of innovation (and then of R&D) in the total cost of producing the final output. In the model, the impacts of knowledge spillovers are consequently more important in countries and sectors that invest more in R&D, with generally greater impacts of international knowledge spillovers on small countries. The impact on GDP following a change in R&D investments, as measured by the model, are also in phase with the empirics. It provides social rates of returns to these investments in the range of 25% to 50%, according to the policy analyzed. This result is confirmed, for instance, in the case of the interim evaluation of the EC H2020 programme, presented in detail in chapter 6. These estimated

social returns are finally rather conservative, being on the lower bound of the values usually measured in the applied literature (see chapter 2, section 2.3.3), close to 90-100%. We will finally emphasize that the approach used to model innovation in NEMESIS does not imply long transitional dynamics, as in the case of QUEST, where semi-endogenous growth leads to very long transitions, with large differences between countries. In NEMESIS, the length of the transitional dynamics is similar in every country, about 20 years. It is the time the growth of knowledge stock, that derives from R&D stocks from various origins, takes to stabilize, following a policy shock, about 15 to 20 years, with a rate of decay of 15% that is assumed for R&D stocks in the model. It also depends on the force assumed of the effects of inter-temporal knowledge spillovers and notably their impacts on the decision to invest in R&D described by equation 5.3.17. This can be governed by using appropriate normalizations of the knowledge stock in this semi-log equation. For the calibration, we therefore always impose, using simulation experiments, that the convergence towards the long-run growth path will always occur before the maximum time horizon of the model is reached.

4.1.3.6 Recent improvements in the model

The innovation mechanisms of NEMESIS presented above are limited to the version of the model with R&D alone. Recent improvements in the model principally concern the extension of these mechanisms to the role played innovation inputs other than R&D. These are presented in the next chapter, where investments in ICT and in other intangible investments other than R&D, namely software and professional training, are also considered. These developments are particularly important as R&D investments lead mainly to technological innovations by industrial firms, while innovations in the other productive sectors, and notably in services that today represent about 80% of EU GDP and employment, are mainly based on the latter forms of investments.

4.1.4 The RHOMOLO spatial CGE model

RHOMOLO is a dynamic Spatial Computable General Equilibrium (CGE) model that is developed and maintained by the Joint Research Center (JRC) - Sevilla unit -, to support the European Commission for the evaluation of structural reforms, growth and cohesion policies, including R&D support programmes, at a detailed spacial level. Based on the modern spacial economic theories, the model describes complex linkages, interactions and spillovers between the different regional economies. A particularly appealing strength of the model is the description of regional bilateral trade flows for ten

different economic activities. The model takes into account local specificities and notably the difference in factor endowment between regions. It is particularly relevant for R&I policies, as the development of these activities may vary greatly across regions.

After a short overview of the current version of the model, this presentation will focus on the way innovation is represented, with a glimpse at calibration issues, and finally some highlights on the model's limitations and possible improvements.

4.1.4.1 Overview of the model's functioning

RHOMOLO distinguishes 267 regional economies with their spatial interactions. Each region contains 10 economic sectors: Agriculture, Forestry and Fishing; Mining, Quarrying and Utilities; Manufacturing; Construction; Wholesale and Retail Trade; Information and Communication; Financial, Insurance and Real Estate Activities; Professional, Scientific and Technical Activities; Public Administration, Education, Health and Social Services; Other Services. In each region, the model is populated by one representative household, one regional government, and firms that operate under pure and perfect, or monopolistic competition, depending on the sector.

On the supply side, firms in the monopolistic sectors produce distinct varieties of goods that are imperfect substitutes. They have constant returns to scale production technologies, but face entry costs. Concerning the production technology, it is represented by a three level nested-CES function, where, at a first level, final intermediate consumption is combined with value-added to obtain final output. Value-added is then split between capital and labor at a second level, and labor is decomposed finally between three different skills (high, medium and low) at a third level.

Concerning households and the labor market, each region in the model is inhabited by one representative household that supplies the three skill categories. The household has CES preferences, consumes all products and saves a fixed share s of its disposable income. There is imperfect competition in the labor market which allows for unemployment. It is also possible to switch, in the model, from a price setting-wage setting functioning (as in QUEST) to a Phillips curve (as in NEMESIS).

The government levies taxes, purchases public consumption goods, conducts investments and allocates transfers to the various agents in the economy.

Concerning external trade, the particularity of RHOMOLO, compared with the two former models, is that trade does not take place with foreign countries, but with other national or European regions. There are bilateral trade flows influenced, as classically in spacial models, by production but also by

transportation costs.

Finally, like for NEMESIS, the high level of detail of the model prevents any forward-looking dynamic, and as NEMESIS it is solved following a recursively dynamic approach.

4.1.4.2 Modeling innovation

In RHOMOLO innovation is modeled in a relatively simple set-up. It relies on both public and private R&D investments. Private R&D decisions are not endogenized in the current version of the model. The manner in which exogenous changes in R&D investments impact in the model pass through two channels: (1) a “*temporary demand effect*” and (2) “*permanent structural effects*”.

The “*temporary demand effect*” is present in all the three models that we presented. It retraces the pure Keynesian multiplier effect that produces in the short-run, a shock on the level of R&D investments. It may also induce inflationary pressures that could impact negatively on economic activity, before the first R&D investments produce productivity improvements.

The “*permanent structural effects*” is productivity improvement. It comes from the accumulation of the public and private R&D stocks that play symmetric roles in the model. We have

$$d\ln(TFP_{rt}) = \sigma_r^{RD} \cdot d\ln(SRD_{rt}) \quad (4.1.40)$$

where σ_r^{RD} measures the elasticity of TFP in the region r to increase in the R&D stock in that region.

4.1.4.3 Calibration of innovation mechanisms

In RHOMOLO Regional R&D elasticities are based on the estimates of Kancs and Siliverstovs (2016, [192]), as non-linear increasing function of the level of R&D intensity in the region. Depending on the region, the value of this elasticity ranges from 0.008 to 0.152, with more than half of the EU regions showing R&D elasticities below 0.01. We can therefore expect very different impacts, at regional level, from a public support to R&D.

4.1.4.4 Limitations and potential for future improvements

The current version of the RHOMOLO model has several limitations concerning the modeling of innovation and the impact that R&D investments have in the model.

Firstly, R&D investments by private firms are exogenous and are not based on expected future returns.

Secondly, R&D expenditures enter the model at a regional level and their effects are not differentiated sectorially. But we know from the literature on R&D and the estimates by Kancs and Siliverstovs (2016, [192]), that the way R&D expenditures impact on the economic performance of firms varies substantially across sectors.

Thirdly, the mechanisms introduced in the model do not represent the knowledge externalities between sectors and regions, but we know from chapter 2 that “*external*” R&D plays a crucial role in explaining the growth of TFP in the different sectors, regions and countries.

Fourthly, public and private R&D investments have identical impacts on the growth of TFP within a region, though their economic impacts should be differentiated: private R&D, like public R&D, adds to the existing stock of knowledge, but furthermore it has the role of allowing the firms to absorb knowledge and transform it into process improvements and marketable innovations.

On these four points, given the current state of the art of applied modeling of R&D in macro models, important improvements could be obtained at a low cost.

Firstly, the endogenization of R&D decision could be introduced in a similar way to that in NEMESIS, with both process and product innovation. It would reinforce the theoretical basis of the model, where in monopolistic sectors, firms are assumed to gain their monopoly position by inventing new varieties of products, but these mechanisms are currently exogenous.

Secondly, the differentiation of the effects of R&D across sectors could easily be introduced using the economic estimates of Kancs and Siliverstovs, as the necessary data are available in the model.

Thirdly, knowledge externalities between sectors and regions could be introduced with diffusion coefficients using for example trade flows, as was already extensively and successfully experimented in the econometric literature on R&D, and also in macro simulation models, as in former versions of the NEMESIS model (Brécard *et al.* 2006, [40]) to grasp international knowledge externalities.

Fourthly, to differentiate the effects of public and private R&D in the model, the most straightforward way would be, as in NEMESIS, to allow the level of the R&D effort of private firms in the different sectors to impact on their long-run growth potential. There is no reason, as seen in the empirical and theoretical literature on R&D, that European R&D policies should have only transitory effects, and could not impact on the long-run growth rate of European regions.

4.2 What do the three models, in the case of “Horizon Europe”, tell us?

This section presents an illustration of the use of the macro models for the evaluation of European Commission R&I policy, with the case of the ex-ante assessment of the socioeconomic impact of the post-2020 EU Research and Innovation Framework Programme, called Horizon Europe²⁰. The key novelty is that this assessment uses the three macro models presented here: QUEST, NEMESIS and RHOMOLO. While NEMESIS has a long track record for the official assessment of EU R&I policies, it is the first time, with this ex-ante evaluation of Horizon Europe, that the QUEST and RHOMOLO models were also employed. The evaluation was performed at the demand of the directorate A5 (Better Regulation and Innovation Principle) of the DG Research, and it was published in 2018 by the European Commission (see EC, 2018, [72]).

The results that we present here are only for the EU as a whole. The results of QUEST at national level were not available, and the results of RHOMOLO were not scaled-up from the regional level to the national one. The results are neither detailed sectorially, as QUEST has no sectorial dimension, and RHOMOLO’s sectorial results were not publicly available. The only feasible comparison of the three models’ results was consequently to focus on the macro European level. The reader interested to detailed national and sectorial results, could nevertheless refer to Boitier *et al.*, (2018, [34]), that present detailed results for the NEMESIS model.

4.2.1 The Horizon Europe programme and its implementation in the models

Horizon Europe is the 2021-2027 research framework programme of EC for R&I, that will succeed H2020 (2014-2020). The general methodology that was followed with the three models, for the evaluation of Horizon Europe, was to consider a scenario called “*continuation*”, assuming the continuation of the current H2020 programme under the next multi-annual financial framework of the EU (2021-2027), excepting the case of “exit” of the UK. The overall budget considered (70 billion²¹, in constant euros

²⁰The presentation here was partly adapted from chapters 5 (on RHOMOLO), 6 (on QUEST), 7 (on NEMESIS) and 8 (on model comparison) of the book “*Macroeconomic Evaluation of Innovation Policies*”, that will be published by Palgrave-Macmillan in 2019 ([10]), from Boitier *et al.* (2018, [34]), and from the article “*The Shape of The Things to Come*” (forthcoming, [277]), that will be published in the Journal for Research and Technology Policy Evaluation.

²¹The funds covered in the study are assumed to have an identical structure around Pillar I, II, III of the H2020 programme and are limited to funds received by Member States - excluding therefore funds received by accessing and

of 2014) is similar to H2020 insomuch as the budget loss due to the “*brexit*” (around 15% of H2020), is compensated by the increase in the EU budget that is expected from economic growth (about 2% per year). Then this “*continuation*” was compared to a “*discontinuation*” scenario, where it is assumed that the EC framework programmes would cease after H2020²².

A first problem that has emerged was the “*financing*” of the Framework Programme. While it was tempting to assume that financing “*appears out from nowhere*”, to isolate its direct impact without other considerations; it was preferred to assume that it was financed from different sources, depending on the assumptions preferred by the teams in charge of the different models. For QUEST, it was supposed that Horizon Europe was financed either by additional Value Added Tax (VAT) revenues in the different Member States, or, instead, by the equivalent lowering of national public investment. For NEMESIS, financing was assumed to come at the expense of lowering national public investment, but by excluding the public funds supporting R&D investments in the different countries. For RHOMOLO, like for NEMESIS, financing comes from cuts in national public investment, but including national R&I support programmes (as for QUEST for its second financing option).

The second problem was the temporal allocation of the Horizon Europe budget. This temporal allocation has to take into account the average length of the projects that the programme would finance. We observe from the previous FP that there exists a large difference between the funds that are committed each year, and the real expenditure in R&I they finance. Taking stock of the first period of H2020 (from 2014 to 2016), the average duration of the projects that were financed is 33 months; it is about the same as for the whole FP7 programme. It was also calculated that 55% of the funds were spent in the first year, 35% in the second, and the remaining 10% in the last year. Therefore, the R&I investments provoked by Horizon Europe should last beyond 2027 (the end year covered by the programme) and continue up to 2029. As displayed on table 4.2.1, the annual allocation of the EC

third countries.

²²The NEMESIS model was also used to evaluate the impact of different sets of policy options surrounding the precise design of the future programme Horizon Europe.

A first set of options concerned the size of the budget. It was 85 billion euros at current prices, for the continuation scenario, but alternative budget envelopes for Horizon Europe were assessed, ranging from 60 billion euros to 160 billion euros at current prices.

A second set of options concerned (de)centralization options, that shifted the R&I effort between the different levels of intervention, i.e. the national and the EU level.

A third set of options changed the design of Horizon Europe compared to H2020, aiming at more impact and openness. This will be achieved through several features such as the European Innovation Council, mission-orientation, strengthened international cooperation, a reinforced Open Science policy, and a new policy approach to European Partnerships.

We won't present the results of the evaluation of all these options, that only concern the NEMESIS model, and the interested reader could refer to Ravet et al. (2019, [277]) for a summary of the results, or to Boitier et al. (2018, [34]) for all the detailed results.

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contribution should increase very progressively, from 1.2 billion in 2021 up to an annual maximum of respectively 13.4 and 13.8 billion in 2026 and 2027, and then decrease, to 6.2 billion in 2028 and to 1.4 billion in 2029. We should underline, that after 2027, the last year of Horizon Europe, it was supposed that the EC Framework Programmes will cease and that the corresponding funds will be sent back to the Member States, following the assumptions above for the different models. The interruption of EU support for R&I after 2027 is of course unrealistic and was assumed in order to isolate the impact of the funds that will be spent for the sole period covered by Horizon-Europe.

Table 4.2.1 – Annual allocation of EC contribution under the Horizon Europe programme

<i>In million € (constant 2014)</i>	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
EC contribution	1,165.1	5,288.3	7,479.1	9,295.9	11,989.6	13,431.1	13,774.8	6,198.7	1,377.5	70,000
- “Basic” research	407.8	1,850.9	2,617.7	3,253.6	4,196.4	4,700.9	4,821.2	2,169.5	482.1	24,500
- “Applied” research	757.3	3,437.4	4,861.4	6,042.3	7,793.3	8,730.2	8,953.6	4,029.1	895.4	45,500

Source: Boitier et al. (2018, [34])

The third problem was, for the specific needs of the NEMESIS model, to separate in the programme the share of the funds that will finance “*Basic*” research, from those that will go to “*Applied*” research. For the evaluation of the FP, it was assumed for NEMESIS that “*Basic*” research would only increase knowledge, while “*Applied*” research would increase knowledge externalities and also help the introduction of process and product innovations in the various production sectors. This split, shown in table 4.2.1, was also based on past FP experience.

The fourth problem was the allocation of the funds between countries, European regions and productive sectors. The allocation of the EC contribution across countries was based on the observed geographical distribution at the beginning of H2020 (2014-2016 period), that was also very close to the distribution observed during the previous FP7 programme. This was, of course, done by excluding the United Kingdom from the calculation. The funds received by the different countries were strongly related to their relative GDP and their contribution to the EU budget, but there were exceptions for some of EU-10 countries. For the regional allocation, it was similarly assumed that it followed the trends in the EU R&I support programme (H2020) at the time. Then, for the allocation between sectors in a country or a region, the “grand-fathering” principle was used, consisting in allocating the

funds in proportion to the contribution of each sector to the total corporate R&D investment in the unit considered (the country or the region).

4.2.2 The adaptation of the R&I mechanisms in the models: Leverage, spillovers and performance

The models also had to be adapted to the specificities of the framework programmes compared to other types of supports for R&I, like those implemented at a national level by the different Member States. Starting with the subsidy for public or private entities, continuing with the R&D expenditures induced by this subsidy, and ending with the economic performance of the “*knowledge*” created by this policy, the mechanisms at play in the models to assess the socioeconomic impact of R&I policies must therefore answer three essential questions:

- What is the total R&D expenditure provoked by financial support: the “*crowding-in*” or the direct “*leverage*” effect?
- What is the total amount of knowledge created by this expenditure and moreover what are the “*knowledge spillovers*” between the different research entities?
- What is the “*economic performance*” of the policy in terms of various economic outcomes: employment, exports and competitiveness, increased production, value-added, GDP, etc?

Each model has its own response to these three questions, depending on the precise R&I mechanisms they embody. But the question finally is: Is there a European Added Value (EAV) because of R&I funding and should the mechanisms of the models be modified to account for this EAV?

In the case of NEMESIS, the parameters of the model were modified to account for this EAV, and it assumed a better leverage of European funding when compared to national ones, inducing more R&I expenditures for the same level of public funding (0.15 instead of 0.1 for applied research, no difference for basic research) and higher research productivity (15% higher, already used in EC, 2012, [115], for the ex-ante impact assessment of H2020), explained by higher competition at the European level than at the national one, and by the transnational collaborative aspects inducing more knowledge spillovers. This EAV was supported by several studies (ECDG and Elsevier, 2017, [112]; Rosenberg *et al.*, 2016, [285]; Vullings *et al.*, 2014, [331]; Delanghe *et al.*, 2011, [97]; PPMI, 2017, [272]). The value used for these “*parameters*” in NEMESIS were considered to be conservative in regard to the

literature, including the following quantified results from PPMI (2017, [272]) based on data from the 7th Framework Programme (FP7) and the first period of Horizon 2020:

- Research organizations supported by FP7 were around 40% more likely to be granted patents or produce patent applications.
- Patents produced by FP7 were of higher quality and more likely had commercial value than similar patents produced elsewhere (70% more citations).
- Patents produced under the Framework Programmes were likely to be of higher technological value and more likely to be based on cutting edge scientific knowledge (11% more citations in non-patent literature, like scientific journals, on FP7).
- Horizon 2020 participants declared that the programme significantly improved their competitive position internationally (78 % expected a decrease in this area if they had not been funded) and access to new markets (71 % expected a decrease in this area if they had not been funded).

In the case of QUEST, no EAV was supposed for the Horizon Europe programme, and the value of the parameters that were retained were identical to that of national R&I funding.

In the case of RHOMOLO, it was assumed, following the assumption used in NEMESIS, that the EU R&I support had a leverage effect of 9.75%, that was the weighted average of the direct leverage effect of respectively basic and applied research in NEMESIS.

We see therefore that the three models correspond to different approaches, but also to different parameter values, and one could not expect that the models will provide the same results for a given policy intervention.

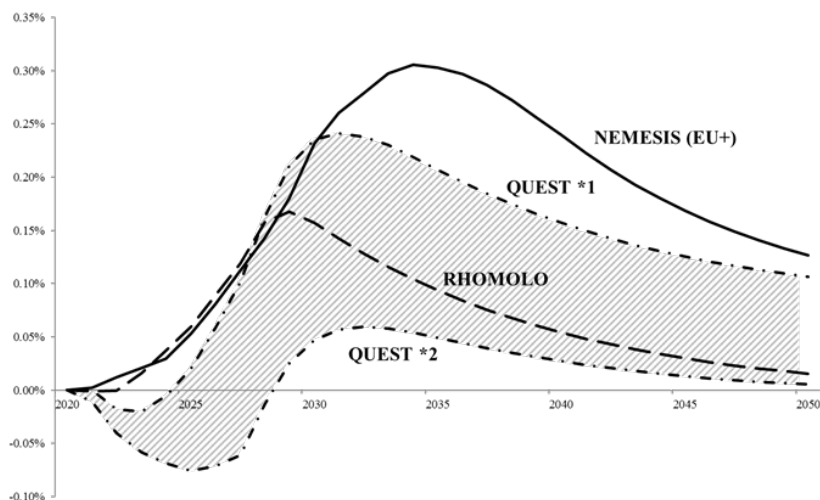
4.2.3 The creation of value (GDP impact) due to continuation

The three models present consistent results in terms of sign and temporal patterns of the GDP gain provoked by the Framework Programme (compared to the discontinuation of the Programme) over 2021-2050²³ (Figure 4.2.1). The three models showed a large increase in the GDP impact during or after the period covered by the Programme, with highest impacts expected between 2029 and 2034. The size of the GDP gains differs and this can be explained by the fact that the three models use

²³We recall that the EU framework programmes were assumed to cease after the end of Horizon Europe (2027) which explains the decrease in GDP in the second half of the simulation of the models.

different sets of innovation channels and elasticities. These results suggested that the continuation of the Framework Programme after 2020 was expected to bring an estimated average GDP increase of up to 0.19% over 25 years, which means that each euro invested could potentially generate a return of up to 11 euros in GDP gains over the same period.

Figure 4.2.1 – The impact of Horizon Europe on GDP



Source: Ravet *et al.* (2019, [277]). Note: QUEST*1 simulation assumed that financing of the programme relied on VAT increase. QUEST*2 assumed that financing relies on lowering public investments.

The highest gains, in the NEMESIS model, can be partly explained by the fact that QUEST and RHOMOLO did directly take into account the performance expected from EU funding of R&I compared to national funding, while this was acknowledged in the parameters of NEMESIS. As explained above, this assumption reflected the intrinsic EU added-value related to the EU level of investments due to factors that were not directly captured by these models, such as multidisciplinary transnational collaborations or critical mass.

Regarding the mode of financing, results from QUEST show that financing R&I investments from value added taxes produced higher economic benefits in the model in the medium and long run than with public investment cuts. This is because the financing mechanism in the model attributed potential productivity effects to public investments (e.g. roads, buildings), that obviously did not exist for value added taxes.

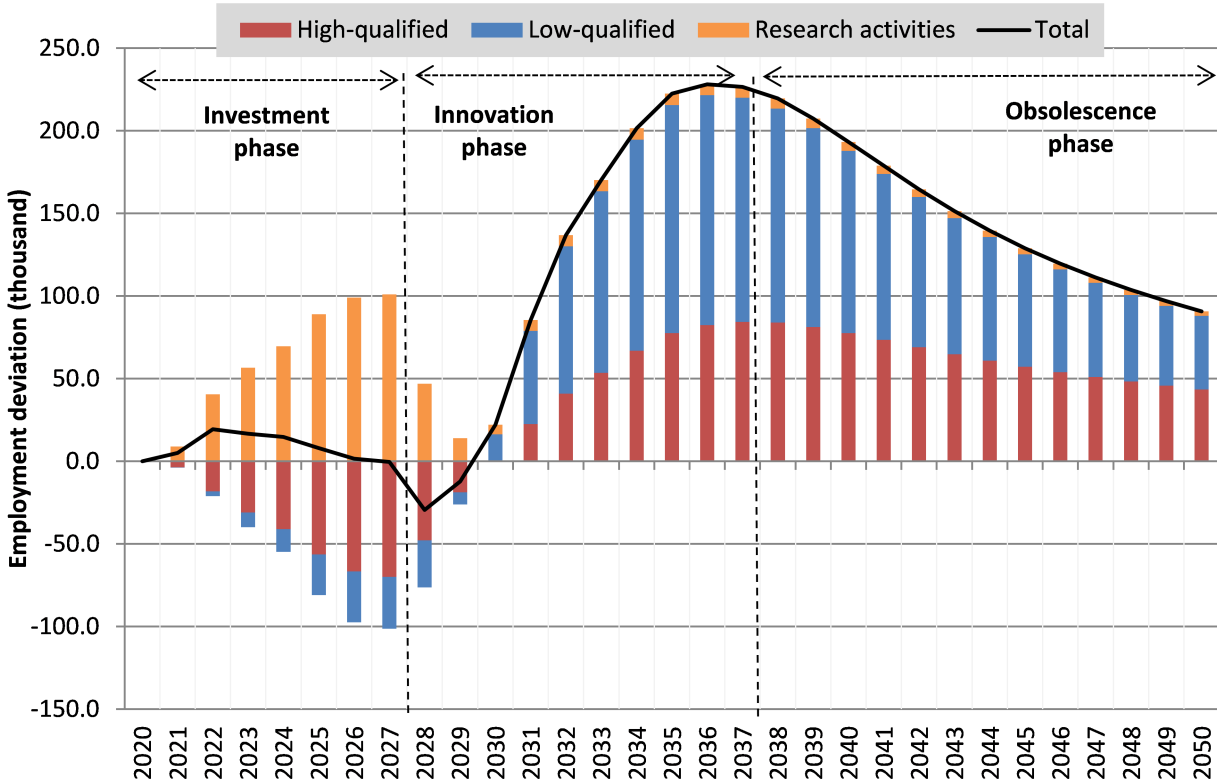
The pattern in time is similar between the models. The NEMESIS model describes this pattern with the following three main phases (see Boitier *et al.* 2018, [34], for more details). (i) An investment

phase over 2021-2027 that is a “demand phase” in which all the dynamics are induced by the change in R&I expenditure, with or without moderated impacts of the innovations (as they take time to appear). This phase can be viewed as a Keynesian multiplier. (ii) Then the innovation phase 2027 up to 2035: the arrival of innovations reduces the production cost of the new products or raises their quality, which induces an increase of demands for products. (iii) Then the obsolescence phase after 2035: new knowledge progressively declines due to knowledge obsolescence and, in the long-term, the macro-economic track goes back to the reference scenario.

4.2.4 Job creations provoked by the programme

To our knowledge, QUEST and RHOMOLO did not produce any public results on employment provoked by the Horizon Europe programme, and so we limit the results to those of NEMESIS.

Figure 4.2.2 – Job creation provoked by the programme



Source: Boitier *et al.* (2018, [34])

The impact on jobs based on the NEMESIS model are substantial (Figure 4.2.2). EU investments in R&I are expected to generate an estimated gain of up to 100,000 jobs in R&I activities in the “Invest-

ment phase” (2021-2027), and to foster, through the economic activity generated by the Programme, an indirect gain superior to 200,000 jobs in 2036, of which 40% are high-skilled jobs. However, during the investment period, though the Programme has a positive effect on jobs in R&I, the decrease in national public investment that is assumed is mechanically accompanied by a comparable decrease in non R&I-related jobs. During this period, the increase in R&I investment raises the demand for employment in research activities. But the funds used to support R&I activities are taken from national public investments according to the assumption used in the model. This shift between both kinds of investments explains the decrease of high- and low-skilled employment while employment in research activities increases. Furthermore, arise in the demand for employment in R&I activities increases the inflationary pressure on high-skilled workers’ wages (as employment in R&I activities are mainly provided by high-skilled workers). This reinforces the negative impact on high-skilled employment in production during the investment phase.

After the investment phase, first there is a negative effect on employment, that is due to a “re-structuration effect”: the first innovations appear that raise productivity and reduce employment, until the fall of the quality adjusted price of products is strong enough to provoke net job creations, from the increase in demand. Then, total employment rises progressively to reach a maximum deviation of +228,000 employments in 2036 compared to a situation without the Framework Programme. Between 2028 and 2036, around 60% of the cumulative EU employment gains relates to low-skilled workers, 30% to high-skilled workers and 10% to employments in research activities. After 2036, the declining economic gains resulting from the EU R&I Programme also reduce employment gains.

4.3 Unresolved issues on the practice of EC R&I policy evaluation using macro models

At the end of this chapter, that presents the three macro models currently used for the assessment of EU R&I policies, and the comparison of their results in the case of the ex-ante evaluation of the next framework programme, Horizon Europe, we will add some comments on the current practice of policy evaluation using macro models.

NEMESIS was regularly used in the past for the ex-ante, interim and ex-post evaluations of EU R&I policies, and these framework programmes. We have seen, the real advantages of NEMESIS for this task: this model is macro-sectorial and econometric, and describes the short-, medium- to long term-

run impacts of the R&I investments provoked by European policy intervention well. This model was calibrated from the start, in the early 2000s, based on careful examination of the economic literature on R&D and productivity, and on the theoretical representation of growth corroborating the main findings in the literature: the key role that in the growth process play (1) inter-temporal knowledge externalities and (2) the necessity for investment in R&I by various firms, sectors and countries, to reach a critical mass in order to be able to transform knowledge into innovations. The model also represents other crucial elements from findings in the specialized literature, such as the very important role in the growth process that the acquisition of technology plays embodied in intermediate and investment goods, as well as the distinct impacts that product and process innovations have on economic performance and employment. Finally, growth in NEMESIS is not “balanced” and there are many channels of structural change, such as the non-homothetic preferences of consumers regarding their choice of products, and the rate of technical change that is extremely heterogeneous across sectors, as R&D investments concentrate on a small cluster of industrial sectors and Knowledge Intensive Business Services (KIBS). Therefore, as illustrated by the literature, the sectors that invest in R&D and develop technological innovations, are not the same that those that adopt and use these innovations.

This richness in terms of innovation mechanisms that the model can reproduce has counterparts, and there is a cost in terms of theoretical robustness, and the overall consistency of the economic mechanisms that the model embodies. On this point, the general equilibrium and forward-looking optimization approach present in QUEST represents a valuable complement. This model has an internal structure that is very close to the theoretical models of endogenous growth, and it guarantees that its results will be conform to the main findings of that theory. But it has also a cost, as the analytical constraints that this modeling imposes, are not compatible with a lot of detail, thus limiting the diversity of the endogenous growth mechanisms that the model could include and represent. Finally, with its high level of spatial detail, the RHOMOLO model represents a useful complement to the two other models, even if its endogenous growth mechanisms remain very limited. Therefore, no model is perfect, and each model usefully complements the other, as it was underlined in the introduction to this chapter, and advocated for example, by Blanchard (2018, [31]).

This being said, models that are based on very different economic traditions, and which represent economic innovation in such different ways, could not provide identical evaluations of EU R&I policies. We saw above, in the case of Horizon Europe, that the GDP gains that the different models estimated

could differ a lot. The estimation is higher with NEMESIS, for three main reasons²⁴ that we recap and comment here:

1. First there are the assumptions retained for the modification of the models' parameters to take the specificity of EU research programmes into account. NEMESIS uses past FP data and evaluations, that provide quantifications of the leverage effect that EU research programmes on the R&D effort of the individual research entities have. This “*additionality*” effect is insignificant and set to zero for basic research, and is estimated at 15% for applied research, against only 10% when the intervention occurs at a national level. EU intervention therefore has an average additionality effect of about 10%. Still from past FP experience, in NEMESIS it is assumed that there was an EAV of about 15%, meaning with a R&I policy support at EU level, the impact is 15% superior than at national level. QUEST does not take into account leverage of EU support on the R&D effort of research units, nor any EAV from this EU support compared to an intervention at national level. Whereas RHOMOLO only considers the leverage effect that EU intervention has, but not its EAV. These differences in their primary assumptions are certainly an important source of divergence between the results of the three models. So, should we build on past experience when evaluating ex-ante EU R&I policies? The robustness of past evaluations of the programmes may also be questioned. But now can we make meaningful comparisons between the models results without harmonizing assumptions on the value of the key parameters.
2. The second point is the financing of the policy measures. For the evaluation of Horizon Europe, it was decided that the EC framework programme “*should not appear out from nowhere*” and that it should be financed. In NEMESIS, we made the choice to reduce national public investments, by the same amount as the EC contribution received by the different countries, and a similar approach was followed in RHOMOLO. It is not very distortive as in these models the multiplier for public investments is about 1. The R&D investments provoked by EC funding increase ex-ante the GDP 1 for 1, as R&D is itself registered as an investment in national accounts. The financing using a cut in public investments is more problematic in the case of QUEST, where it is assumed that public investments provoke increasing returns in the production function for

²⁴There is also the fact that in the version of the NEMESIS model that was used for this assessment, that we present in the next chapter, innovations come, besides investments in R&D, from investments in ICT and in intangible assets other than R&D like Training and Software. As we showed in chapter 6, in the case of the interim evaluation of H2020, this new version of the model slightly increases the results for the GDP, compared to the version of the model with R&D only.

final output. We see in this case (figure 4.2.1) that the effect of the EC research programmes are nearly totally canceled out, with GDP impacts that are first negative and only slightly positive thereafter. Financing using an equivalent increase in VAT is less distortive, and it allows the impact on EU GDP measured by QUEST to increase significantly and come closer to the one measured by NEMESIS. So we see that financing assumed for policy intervention is not neutral, and may confuse the interpretation of the models' results. Then, when evaluating EU R&I policies: Why not consider the case where financing of the intervention “*appears out from nowhere*” as a benchmark simulation, and allow evaluation its impacts *per se*, without any other consideration?

3. The last point, and certainly one of the most important for understanding the differences between the models' results, is the way innovation is represented in them. We have seen than in NEMESIS innovations have two effects: they increase the productivity of firms in the sectors, and the quality of the products they put on the market. From the literature, it has been established that process innovations have only small output and employment effects on the macro level, compared to product innovations. In NEMESIS, the “*share*” of product innovations is set at 33%. As we will see in the next chapter, if we remove product innovations in the model, the long-run impact of a positive shock on firms R&D investment is reduced by more than twice, and the employment effects by more than four times. Process innovations have an important initial detrimental impact on aggregate demand and employment in the model, which greatly lowers the fruit of an R&D policy. As QUEST only retains this later type on innovation, it is not surprising that the model has a very limited impact on employment and economic performance of R&I policy interventions. For example, we see from table 4.1.2 that a tax credit leading to an 0.1 GDP point increase of private R&D would lead with QUEST, after 35 years, to an increase of GDP of about 0.25% in Spain, 0.18% in France, 0.32% in Germany and 0.13% in Austria. For employment, we respectively have from Sanchez-Martinez *et al.* (2017, [289]), about 0.025%, 0.05%, 0.04% and 0.045%. For NEMESIS (see chapter 5, tables 5.5.6 and 5.5.7), a shock of 0.1 GDP point on private R&D in 2015 would lead in 2050 to an increase of EU GDP of about 0.52%, and of EU employment of about 0.24%²⁵. That is superior, but still very close to QUEST for GDP (about two times), but with a much wider gap for employment (about six times). If we remove product

²⁵In reality, the shock is 0.5 GDP point, and all the percentages here were divided by 5.

innovations, the impacts of the shock on EU GDP and employment are now respectively 0.24% and 0.06%, that is to say, very close to QUEST results. For RHOMOLO, we do not dispose of analytical tests like these, but the very low impact of Horizon Europe on GDP calculated by the model certainly has the same origin. This is reinforced by the fact that it is assumed in RHOMOLO that the TFP elasticity of R&D is the same in every sector. Assuming the same elasticity in service sectors as in industrial sectors, it would be very destructive for employment in the latter. So, the last question is: Why should we only consider the effects of process innovations in the models and not those of product innovations, when assessing for EU R&I policies?

Chapter 5

Beyond R&D: A New Framework for NEMESIS

5.1 Introduction

In this chapter we present the new innovation module that was introduced in NEMESIS, as the result of the FP7 EC research project SIMPATIC¹. This new module takes advantage of the most recent findings of econometric studies, at micro, meso and macro levels, aiming to demonstrate the enabling features of ICT, and the complementarity of investments in ICT, and investments in intangible assets.

As illustrated in chapter 4, until now the endogenization of firms' innovation in applied simulation models was limited to R&D. It was based on widely accepted justifications for government intervention in the field of *R&D* policies, enlightened by the New Growth Theories *à la Romer*: positive knowledge externalities coming from R&D activities. The hypothesis introduced by Bresnahan and Trajtenberg (1995, [43]), of ICT as GPT, bridges this approach with the one of industrial organization, and therefore widens the scope of policy intervention to positive externalities arising from different network effects: from the interactions between (1) producers and users of the GPT, (2) users' co-inventions, and (3) users' investments in complementary assets.

We use original methodologies, mainly based on patent citation techniques, to explicitly represent both the knowledge externalities from *R&D* activities and the network externalities between the users of ICT, with three dimensions: intra-sectorial, inter-sectorial and international. Externalities between producers and users of ICT are taken into account by the backward and forward linkages between sectors captured by the transaction matrices of the model. These externalities, up until now poorly retraced in econometric works, in our structural modeling represent an important complement to this point, that future studies could re-use and develop, when focusing on inter-sectorial and international interactions with structural data such as WIOD (Timmer *et al.*, 2007, [309, 310]), EU-KLEMS (Timmer *et al.*, 2007, [309]) and INTAN-INVEST (Corrado *et al.*, 2014, [73]).

This new frame is particularly well adapted to represent innovation in service sectors, and also the growing importance of the phenomenon of "tertiarization" in the manufacturing sector. The development of broadband and information technologies puts the emphasis on the major role played by service sectors in innovation today, that are the principal users of ICT and investors in non-R&D intangible capital. What is more, an increasing part of industrial value-added also comes from the sale of services, where investment in ICT and intangible capital plays a major role.

This chapter provides a first attempt to integrate these new features in the NEMESIS model

¹grant agreement n°290597, FP7

designed for EU R&I policy assessment. Section 5.2 first summarizes the key findings in the new growth accounting literature, notably works illustrating the important contribution of ICT capital deepening to productivity growth in OECD countries in recent years. It also describes the new conceptual framework proposed by Bresnahan and Trajtenberg (1995, [43]) with the concept of “ICT as GPT”, to represent these new phenomena. It finally sums up the main findings concerning the GPT features of ICT. Two main points are notably investigated:

1. First, if there is “*excess*” (or “*above normal*”) returns on ICT investments, that would be a first justification for the theoretical assumption that there are for ICT, specific endogenous growth mechanisms and spillover effects leading to non decreasing returns, as for R&D.
2. Second, whether as suggested by the new theoretical framework, there are complementarities between the different innovation inputs: ICT, RD and Other Intangibles (OI) than R&D (software and training in this setting).

Then, section 5.3 describes the new framework to represent innovation in NEMESIS, based on the “ICT as GPT” hypothesis, and on an innovation function combining different innovation strategies, based either on R&D, on ICT, or on OI investments. The way it was implemented in NEMESIS is presented in section 5.4, on calibration and data. Section 5.5 finally illustrates this new innovation module, with the results of analytical tests. These tests show the distinct sectorial and macro-economic impacts that each of the three innovation inputs (ICT, R&D and OI), have on output and employment. Their analysis confirms (1) the strong ripple effect that ICT investments have on the two other categories of assets, and that (2), while the direct impacts of R&D investments remain concentrated in industry and R&D intensive countries, investment in ICT and in OI are more inclusive in terms of sectors and countries, in the sense that the benefits are more widespread.

5.2 Broadening the framework with the concept of ICT as GPT

At first controversial, the strong positive impact of ICT on economic development is nowadays widely recognized and a “Digital Revolution” is at work. The Controversies notably arose from the lagged impacts that investments in ICT technologies have on the firms performance. A new theoretical frame was developed, insisting on the enabling feature of ICT as technologies that need complementary

investments, in a set of intangible assets, such as training or organizational capital, in order to produce their full impact on innovation and the evolution of labor productivity. This section retraces the most crucial elements of these findings, which motivated the general methodology presented in the next section for reshaping the representation of innovation in NEMESIS.

5.2.1 Theoretical grounds²

The idea that economic evolution is strongly influenced by innovation and technical change is far from new and was notably developed in the works of J.A. Schumpeter (1939 [293], 1942 [294]). Later, the central role played in this process by the existence of non-decreasing returns was formalized (Romer, 1986 [283]) and appears with the New Endogenous Growth theories, explaining these non-decreasing returns at macro level, thanks notably to knowledge externalities arising from the R&D efforts undertaken at the micro level (Romer, 1990 [284]; Grossman and Helpman, 1991, [152]; Aghion and Howitt, 1992 [4]). This formalization brought very valuable tools for the understanding of long term economic growth. However, it describes a continuous growth path whereas, in reality, the process of growth is discontinuous and heterogeneous, and it was strongly challenged by the emergence and wide diffusion of ICT in the last quarter of the twentieth century.

5.2.1.1 Growth accounting and the productivity paradox

Several years after the beginning of the “*digital revolution*”, the economic performance did not meet expectations, since growth in productivity stagnated at a relatively low level in most modern economies. Despite this, the “*revolution*” was soon evident through the wide diffusion of the computer and the proliferation of new digital products, such as internet, mobile phones, online services, etc., though at first, it did not materialize in macroeconomic statistics on growth and productivity. This productivity paradox was perfectly summarized by the witticism of Solow (1987 [302]) in the New York Times: “*You can see the computer age everywhere but in the productivity statistics*”, and this contradiction almost became pessimistic for some, like Krugman (1994 [200], p173), who wrote: “*Something is out of kilter here. Either the technology is not all it’s cracked up to be, or we haven’t yet seen the impact of new technology on the economy. [...] my own view is more pessimistic [...] and I worry that productivity growth may actually decline*”. Some authors pointed out to underline this, that non-

²This section builds partly on Le Hir (2012, [205]) concerning the presentation of the concept of GPT, as does the paper by Le Mouël, Le Hir, Fougeyrollas, Zagamé and Boitier (2016 [209]).

manufacturing ICT-using industries were incurring a labor productivity slowdown, highlighting the effects of Baumol's disease (Baumol and Bowen, 1965 [23] and Baumol, 1967 [22]) in non-progressive service industries despite their intensive use of ICT, and this last observation led Gordon (1998 [133]) to think that *"there is something wrong with computers"*. This productivity slowdown was reinforced by the large redeployment of economic structures from manufacturing industries towards service industries in developed countries, over the second half of the twentieth century.

However, after a period and with the development of better accounting methods made possible by the availability of new data-sets on ICT investments at national and sectorial levels, these over-pessimistic statements became nuanced. While the first study by Oliner et al. (1994 [256]) displayed the minor impact of hardware equipment on labor productivity growth in the United States for the period 1970-1992, Jorgenson and Stiroh (2000 [186]) showed, for the period 1995-1999, that this contribution was higher, if was the price of hardware better adjusted for quality improvements. In addition, Oliner and Sichel (2000 [254]), by extending the measurement of ICT by including software, evaluated the contribution of ICT capital deepening to 2/3 of the 1 point labor productivity step-up in the second half of the 90s. This finding was then confirmed by Jorgenson and Stiroh (2000 [186]), Oliner and Sichel (2002 [255]), and Daveri (2003 [90]). The sectorial decomposition indicates that this acceleration of productivity in the United States, during the second half of the 90s, was mainly concentrated in ICT producing and ICT intensive using industries. In Europe, where ICT diffusion is lower, labor productivity growth did not experience this kind of recovery, that corroborates the predominant role of ICT in the US productivity resurgence. So in 2000, as Jorgenson and Stiroh (2000 [186]) pointed out, the *"pessimism of the famous Solow paradox [...] has given way to the optimism of the information age"*.

During the second half of the 90s, ICT capital deepening continued to be strong and Jorgenson *et al.* found (2008 [185]) that labor productivity growth increased particularly in ICT using sectors. This is in line with the results of Colecchia and Schreyer (2002 [68]), that showed the important role of ICT diffusion for productivity growth in OECD countries, with a particularly important impact on service sectors after 1995, as did the works of Bosworth and Triplett (2007 [37]), and van Ark, O'Mahony and Timmer (2008 [316]).

All these pioneering studies therefore brought the important insights (i) that *"disposing of a large producing ICT industry is neither a necessary nor a sufficient condition to experience successful effect of ICT on growth"* (Colecchia and Schreyer, 2001 [67]); (ii) that a sectorial approach is necessary to

retrace the impacts of the diffusion of ICT in using sectors and (iii) that the US-EU productivity gap after 1995 can be explained to a large extent by the under-investment in ICT in European countries. But empirical observations still reserved surprises. Following the burst of the dotcom bubble in 2000, ICT investments slacked off and this suggested to economists that productivity growth might slow down again over the next several years. But this was not the case in the US. This new paradox, again, reflected, matter-of-factly, the need for more complete explanations rather than just a description of evolution. For this purpose, the concept of General Purpose Technology (GPT) provides valuable clues.

5.2.1.2 Multidimensional Innovation and the GPT concept

The observation of the acceleration of TFP in the 2000's in ICT using sectors, and its slowing down in ICT producing sectors (see Corrado, Lengersmann, Bartelsman and Beaulieu, 2007 [77]; Bosworth and Triplett, 2007 [37]) is a good illustration of the limitations of the ability of the growth accounting approach to explain the economic growth in the last decades. It brings useful information on the role of capital deepening for labor productivity growth. But, as pointed out by Archaya and Basu (2011 [2]), it gives, by definition, no explanation on the reasons why the TFP is accelerating in services and other ICT using industries: *“According to this theory, the fall in input prices does not shift production functions of the output sector. Of course, the fall in price leads to ICT capital deepening throughout the economy boosting labor productivity in ICT-using sectors, but does not change TFP in sectors that only use but do not produce ICT”*. The intuitions are then that *“the resulting ICT deepening may lead to more use of complementary intangible capital [which is unaccounted for as inputs] and (...) that there might, in fact, be presence of positive externality of ICT use”*.

For that purpose, the concept of General Purpose Technology (GPT thereafter), first proposed by Bresnahan and Trajtenberg (1995 [43]), offers an attractive conceptual tool for explaining both (i) the time lags necessary from the introduction of new major technologies before they produce their first significant positive impacts on productivity and (ii) their impact on TFP in using industries. The term of GPT concerns radical technical changes that affect the whole economy and *“transform both household life and the way in which firms conduct business”* (Jovanivic and Rousseau, 2005 [187]).

In order to grasp the concept of GPT concretely, the parallel between Information Technologies and the Electric Motor developed by David in his article: *“The dynamo and the computer: an historical perspective of the modern productivity paradox”* (1990 [92]), is particularly meaningful. It notably

depicts how the switch from the steam engine to the electrical drive system, at the beginning of the twentieth century, paid off only after several stages. During the first stages of adoption, the productivity of the production units, still driven by a central motor unit and a transmission shaft, was not improved, only the energy source changed. It is only after the invention of the unit drive system, in the 1920s, that the production process could be redesigned and that we saw the impact on productivity. The effects, that *“revolutionized manufacturing by decentralizing the source of power and making possible flexible and portable tools and machines”* (Gordon, 2000 [134]), were even more important than expected. According to David (1990 [92]), *“The advantages of the unit drive for factory design turned out to extend well beyond the savings in inputs of fuel derived from eliminating the need to keep all the line shafts turning, and the greater energy efficiency achieved by reducing friction losses in transmission”*. David (1990 [92]) describes a lot of additional positive impacts for firms, which, besides savings in fixed capital, result principally from major organizational innovations, such as: the optimizing of machine placement and, therefore, the reduction in handling operations; the reduction of losses during maintenance since an intervention on an individual machine becomes possible without shutting down the entire power system; the implementation of a continuous production process like in chemical industries. Industrial applications for households were also radical, if one thinks, for example, of washing machines, refrigerators and air conditioning. This type of in-depth change of the production process and household devices following the adoption of a new technology is defined in evolutionary economics (Freeman and Soete, 1982 [?, 127]; Perez, 1983 [267]; Freeman and Perez, 1986 [126]) as a change of techno-economic paradigm, and, in the case of the computer, we are still probably in the transition period that may lead to another new techno-economic paradigm.

The theoretical implications stemming from these historically grounded representations of technical change are numerous. While Bresnahan and Trajtenberg (1995 [43]) recognize the important contribution of the models à la Romer for the representation of endogenous growth, at the heart of which is the role played by increasing returns created by knowledge externalities arising from R&D activities at microeconomic level, they nevertheless consider that most of these models are *“flat”*, *“(...) in that they do not allow for explicit interactions between different sectors. Thus, the locus of technical change would not seem to matter, and hence there is no room to discuss explicitly issues of coordination, market structure and aggregate growth. Closely related, technical change is often assumed to be all-pervasive, that is, to occur with similar intensity everywhere throughout the economy”*. By contrast, the concept of GPT identifies particular sectors (those that develop GPT), that are *“critical in fostering*

technical advance in a wide range of user industries, and hence presumably in 'driving' the growth in the economy at large". In such a context, "*Time gaps and time sequences [become] (...) an inherent feature of technological development [requiring] (...) coordination between agents located far from each other along time and technology dimensions*". Therefore, added to the traditional "Knowledge" and "rent" spillovers as formalized by Griliches (1971 [139] and 1979 [141]), GPT creates important additional sources of spillovers arising from the technological complementarities existing between the GPT producing sectors and the GPT using industries, that evolve in two different directions:

1. Vertically: GPT producers create new opportunities for developing innovations in the user sectors, that may be either technological or organizational, like in the case of the Electric Motor described by David (1990 [92]). Reciprocally, the applications developed by each user sector of the GPT increase the demand for the GPT, and therefore generate strong incentives for GPT producers to invest in research and development, as formalized in Bresnahan and Trajtenberg (1995 [43]) and in Carlaw and Lipsey (2002 [52]).
2. Horizontally: within user sectors which deal with the fact that the more users there are, the larger their demand for GPT, the larger will be the incentive to invest in the GPT producer sector, as described above, which, in return, will benefit other downstream application sectors. Thus, "*this externality stems from the generality of purpose of the GPT*" as explained by Bresnahan and Trajtenberg (1995 [43]). In addition, knowledge externalities between user sectors emanating from their co-inventions in GPT can evolve, like in Helpman and Trajtenberg (1998 [160]).

In that way, the concept of GPT extends the concept of spillovers, present in the first new Endogenous Growth models *à la Romer*, to the externalities arising from the "*strategic complementarities*" existing both between GPT producers and GPT users, as well as within GPT user sectors. It characterizes a situation, originally established in the game theory framework by Bulow *et al.* (1985 [49]) and in the industrial organization theory (Maskin and Tirole, 1987 [237]), where decisions by two or more players reinforce the other players. Technological complementarities strongly magnify externalities, but the kind of externalities conveyed by technological complementarities create a lot of inertia and coordination problems within the system: when things evolve *favorably*, a long term dynamic develops consisting of large-scale efforts in research activities where social and private marginal returns attain high levels. In the other cases, the system is likely to become trapped into a very low level of research investment in all sectors. This structure of externalities furthermore creates several delays: between

GPT “*inventions*” and the first GPT “*co-inventions*”, between “*co-inventions*”, further investments in the basic inventions, and the generalization of “*co-invented ideas*”. This refers to the time gaps and time sequences Bresnahan and Trajtenberg (1995 [43]) pointed out, which is necessary for a new GPT to drive “*growth in the economy at large*”, and for the idea that the diffusion of a GPT may create a greater or lesser force on economic growth depending on its environment. The economic environment must not only be conducive to the diffusion of GPT but also to the development of complementary innovations enabled by previous externalities. Nowadays innovations do not take place in just one sector (R&D), but influence many sectors of the economy. This also extends the role of public intervention to the prevention of coordination problems posed by both vertical and horizontal externalities.

In view of the mechanisms underlying the concept of GPT, three fundamental criteria exist in technology to be included in this concept (Lipsey et al. 2006 h [222]³):

1. Improvement: The GPT must have a large potential for development;
2. Pervasiveness: there must be a widespread use of the GPT across sectors;
3. Ability to spawn innovation: a GPT must create a lot of innovation opportunities in user sectors.

Considering ICT as GPT implies that ICT must fill all these GPT criteria as examined notably by Jovanovic and Rousseau (2005 [187]). The first two conditions appear to be present, as there is firstly a strong decrease in the quality adjusted price of ICT equipment goods and, secondly, because of the important share taken by ICT in capital stock and value-added, in most advanced countries and production sectors, shown in the growth accounting literature. The last criteria is the most important, but also the most difficult to prove, as innovation opportunities in user sectors of the GPT take on various forms. In addition, as mentioned by Nordhaus (1997 [252]), “*The essential difficulty arises from the obvious but usually overlooked reason that most of the goods we consume today were not produced a century ago*”. Surveying the literature on Information Technologies and Productivity, Brynjolfsson and Yang (1996 [46]) report that “*the sorts of benefits that managers ascribe to information technologies - increased quality, variety, customer service, speed and responsiveness - are precisely the aspects of output measurement that are poorly accounted for in productivity statistics as well as in most firms accounting numbers (Brynjolfsson, 1994 [47])*”. It is therefore possible that the innovation potential

³They identify four features but we group two of them together in the second feature to underline the ubiquity of technology.

and the “*Ability to spawn innovation*” in user sectors, are both considerably underestimated in official statistics.

If the GPT concept is revealed to be an important tool for explaining Solow’s productivity paradox, the enabling features of ICT, and the role played by complementary assets such as organizational capital or training, need additional confirmation. Recent developments in the literature provide some important elements.

5.2.2 Can ICT really be considered as GPT? - The empirics

The first statement to come out from the innovation mechanisms described above, is that innovation is the consequence of efforts of very different natures, whose scope a lot wider than that of pure R&D investments. But, what do the data and the econometric studies on these phenomena tell us?

5.2.2.1 What do the data and the stylized facts tell us?

Despite the improvements achieved in data collection initiated notably by the OECD, since the introduction of the Oslo manual on innovation in 1992, data on innovation inputs and outputs are still very scarce, which represents an important limitation for empirical studies. Recently, the development of the Community Innovation Survey (CIS) in Europe contributed very valuable information on firms’ innovation strategies, as did the Yale survey (Levin *et al.*, 1987 [215]) for US in the 80s. Since its introduction in 1992, the CIS has greatly improved, especially in its third edition that covers the period 1998-2000, by adding information on non technological types of innovations (process and product), such as organizational and marketing innovations, but only for firms that introduce technological innovations. The coverage on the database was then extended to all firms since CIS 6 and the revision of the Oslo manual in 2005 (see Vergori, 2013, Mairesse and Mohnen, 2010 [230]), producing a better description of innovation in service industries. The CIS is linked in most studies with firms’ data from national statistical offices, permitting the measurement of innovation outcomes such as the impact on firms’ sales, productivity and employment. Therefore, the CIS constitutes an important complement to the other existing databases related to innovation like R&D surveys or patent databases such as PATSTAT.

Regarding the macroeconomic and macro-sectorial aspects, major improvements came from the construction of the EU-KLEMS database, that notably provides time series from 1970 onwards on IT, CT and software for up to 18 OECD countries in 34 industries, as well as from INTAN-INVEST

(Corrado *et al.* 2012 [74]; Corrado *et al.* 2014 [75]) that provides time series (1995-2010) on private investments in intangible assets for every EU-28 country, plus Norway and US at national level, and at sectorial level for 14 EU countries (10 sectors), following the three broad intangible categories identified by Corrado *et al.* (2005 [76]): (i) Computing information (mainly software), (ii) Innovative properties (mainly R&D) (iii) Economic competencies (expenditures in brand equity, organizational improvement or firm specific human capital).

The statistical analyses of these new data sources provide the first proof of the wide categories of strategies used by firms to innovate, and of the important role of complementarity between different innovation inputs.

Regarding the multidimensional aspect of innovation activities, using the CIS 3 that covers 13,055 firms in 13 countries, Srholec and Verspagen (2012 [303]) show at micro level; with a Factor and a Variant Components Analysis; that firms that base their innovation strategies “*predominantly on the research ingredient are, clearly a minority*”, and that most the firms base their innovation strategies at least on three of the four innovation ingredients they identify: (i) “*Research*” (R&D and knowledge intensive related inputs and activities), (ii) “*User*” (Product effects, associated with the introduction of nontechnical changes in the enterprise, such as organization structure or marketing), (iii) “*External*” (Opportunities coming from the diffusion of technologies embodied in capital goods and acquisition of external technologies), and (iv) “*Production*” (involving process innovations together with a need to live up to the demands for responsibility of the firm). The authors furthermore show that the heterogeneity of innovation ingredients and the strategies used to innovate are explained for more than 83% to 95% by the heterogeneity prevailing at the level of the firm. Nonetheless, while they find, in line with Leiponen and Drejer (2007 [214]), that “*industries tend to be very mixed bags on innovation strategies*”, the differences between countries and sectors⁴ were found to be significant.

At macro level, the analysis of the new INTA-INVEST database on intangibles similarly confirms how n have become intangible assets, in recent years, with investment rates that are close to those of tangible assets, or even exceed them in some cases, like in US and UK (Corrado *et al.* 2012 [74]). These investments are also widespread in production sectors, but there are differences between countries and sectors. Corrado *et al.* (2014 [78]) extend the growth accounting approach to intangibles for 8 countries for the period 1995-2005, to notably show that: “*(a) intangible investment has grown in*

⁴The authors use a disaggregation in 26 sectors, close to the nomenclature of NEMESIS

manufacturing and services, but most strongly in services (...) (b) the contribution of intangibles to labor productivity growth is similar in both manufacturing and services and in the high growth economies (Austria, Germany, Finland, France, Netherlands, UK) exceeds the contribution of labor quality (...) (c) the very large size of the service sector means that countries with good manufacturing but poor service productivity growth (Germany and France) have done relatively badly overall and those with good service sector growth (UK, Netherlands) have performed well (and that) (d) Spain and Italy have very low labor productivity growth due to very low TFP growth”.

These results, therefore provide a first justification to our attempt to extend the representation of innovation strategies in NEMESIS to investments in ICT and in OI in addition to investments in R&D.

Concerning *“the appropriate level of abstraction”* to quote the words of Mann (2011 [232]), that is to say the most appropriate disaggregation level between micro, meso (sectorial) or macro, the GPT concept, in which the interactions between users and producers of technologies, as well as the *“technological complementarities”* between sectors, are central suggesting that the meso approach is necessary to grasp the result of micro behaviors on the macro-economy. With this point of view, a model such as NEMESIS, that details economic activities into 30 production sectors, has an important role to play in bridging the micro and macro dimensions, as claimed for example by Dopfer (2011 [105] and 2012 [106]) in reference to Schumpeter (1942 [294]): *“What emerges is a meso unit that gives micro its distinct position, and that constitutes the building block for the construction of macro. In this view, the course of formulating the theory is not from micro to macro, but – with no short cut possible - from micro to meso, and from meso to macro.”*

Moreover, the development and the diffusion of ICT is likely to have deeply influenced the sectorial composition of the economy as well as the innovation strategy of firms, and also to have modified linkages between the different sectors of the economy, notably between the manufacturing and service sectors. In his study, *“More than making things”*, Sissons (2011 [297]) describes the transformations in the manufacturing industry provoked by close producer-customer interactions, that the author calls *“manuservices”* and illustrates by *“An ownership model where the customer does not own a good, but pays a regular fee to rent it or derive a service from the good, [implying] (...) a redistribution of risk between buyer and seller, with the producer bearing more of the risk associated with a product and (...) longer service contracts instead of a series of one-off transactions. [By this way] (...) manufacturers develop relationships with customers, rather than interacting in a transactional style and, (...) increased customer involvement in designing and producing goods (such as bespoke manufacturing)”*. According

to Sissons (2011 [297]), in UK , manufacturing firms generate 15% to 20% of their revenues by selling services, and manu-services represent about 2% of GDP. He finds that the proportion of firms that “servitized” is around 28% in UK, which is far lower than in US where this share is equal to 55%.

5.2.2.2 The contribution of econometric studies

In addition to these statistical studies that highlight how the digital age is reshaping the economy, econometric studies investigate the existence of excess returns associated with ICT and with various intangible investments, while trying also to provide evidence of the strategic complementarities mentioned above. This econometric literature is still limited, because of the scarcity of the data that need to be improved, but there are already important elements that confirm the two main points: (1) the excess returns to ICT investments and (2) their complementarity with investments in OI assets.

Are there, like in R&D, excess returns associated with ICT?

Regarding the excess returns on ICT investments, Biagi (2013 [30]) and Lopez and Mairesse (2011 [223]), provide extensive surveys on the question, and the meta-analysis from Stiroh (2002 [305]), covering 20 studies for different periods and different groups of countries and industries, gives the first interesting results.

Stiroh (2002 [305]) estimates in his meta-analysis that the mean elasticity of output to ICT capital is about 0.05, but with quite a high standard deviation (0.05). In particular, he finds that (1) studies using the more recent data tend to show higher elasticities, partly because ICT diffusion has increased over time, (2) the magnitude of elasticities is twice as important when value-added is used instead of production for measuring output, (3) elasticities increase with the level of aggregation of the data, suggesting the presence of externality effects or of variables, not taken into account in the analysis. In addition, Stiroh (2002 [305]) confirms this finding by conducting various econometric estimates on US data with various levels of aggregation and different estimation techniques. Notably he shows, by breaking ICT between IT and non-IT capital stocks, that, while non-IT elasticities are inferior to their value-share or not significant, IT elasticities are superior to their value-share. These first econometric results thus tend to confirm “*excess*” returns of ICT capital, coming from the IT share. The higher the level of aggregation, the more the elasticities increase, giving a strong indication of the presence of externalities associated with the use of ICT.

Lopez and Mairesse (2011 [223]) also investigate the output elasticity for ICT capital at macroe-

conomic level, using a panel of 20 OECD countries over the period 1985-2004. The originality of this study is that it jointly estimates the output elasticity of ICT and R&D capitals, and it shows that the elasticity relative to ICT is greatly modified when we omit the R&D variable in the production function, supporting the idea that these two types of investments may be complementary. This result is re-enforced by the fairly large range of elasticities estimated depending on the country, with generally higher ICT elasticities in countries where the R&D capital stock is higher, and vice-versa. Output elasticities with respect to ICT range from 0.1 and 0.18, and those with respect to R&D between 0.07 and 0.16. Moreover, they find that elasticities increase with the level of aggregation, once again suggesting the existence of externalities. At macro level, the results are very close to Ketteni et al. (2007), that use macro data from 15 OECD countries from 1985 to 2004, and find value-added elasticities with respect to ICT capital between 0.18 and 0.26.

Van Reenen *et al.* (2010 [320]) find, at the firm level for a panel of 13 EU countries for the period 1998-2008, elasticities of output to ICT capital ranging from 0.023 and 0.09, which is in line with the previous results of Brynjolfsson and Hitt (2003 [48]) estimated for the U.S. over the period 1987-1994.

Though, if most results indicate that ICT have a strong impact on productivity, they also give a wide range of values for the estimated elasticities, influenced by a wide range of omitted factors in the analysis. So the results show that there are probably externalities coming from ICT and complementarities with other assets, but they cannot really model these effects. This can thus lead to biased estimates.

Are there ICT and OI externalities and complementarities between ICT, OI and R&D?

ICT externalities are generally introduced into the analysis as cross-effects between the aggregate ICT capital stock and the productivity of ICT capital at sectorial level, or as cross-effects between the ICT stock of the firm, or the sector, and other inputs of the production function. Unfortunately, the studies investigating the impact of complementary assets on productivity and output growth are very few because of the scarcity of databases on intangibles.

An important contribution to the analysis is provided by Corrado *et al.* (2014 [75]) who developed the INTAN-INVEST database which breaks down intangible investments into 10 business sectors. The authors cross the INTAN-INVEST and EU-KLEMS databases for the period 1998-2007 and 10 EU countries, and provide the first important results at macro level on the role of intangible assets, complementary to ICT, for productivity. They find that the productivity impact of ICT is increased

when complemented by intangibles, and that non-R&D intangibles have, as we just reported for R&D and ICT capitals, higher estimated output elasticity than their input shares, implying that they also produce positive spillovers. The authors explain that these results are in line with the “*cross country source of growth literature*” revealing a strong correlation between intangible capital deepening and productivity, as in Corrado *et al.* (2012 [74]), or in Roth and Thum (2010 [287]).

In another study using the labor force survey data on training and the EU-KLEMS database, O’Mahony and Peng (2010 [257]) find, for EU countries at sectorial level, a significant positive impact of training on productivity. They find, in particular, that part of this impact comes from interactions with ICT and is heterogeneous between industry and services. For the authors, “*This is consistent with a recent literature that emphasizes the role of organizational changes and associated retraining of the labor force in diffusing new technologies*”.

Crass and Peters (2014 [80]), using firm level data for Germany for the period 2006-2010, also find important productivity impacts of training, with more important effects than R&D and marketing in the short term, whereas in the long term, they find an important impact of innovative capital goods in conjunction with human capital on productivity growth.

Similarly, Bresnahan *et al.* (2002 [45]) find important complementarities between ICT, human capital, decentralized work practices, and product and process innovations. They underline the important role played by IT investments in provoking organizational change, and in raising firms’ investment in human capital (skill bias).

Crespi *et al.* (2007 [82]) show, for the UK using the CIS 3 (1998-200), significant returns to IT capital (30%) when we do not “*control*” for organizational capital, as IT and organizational capital jointly have a strong impact on productivity, but no impact separately. Polder *et al.* (2010 [270]) find similar results for the Netherlands, using CIS 3 to 5, with strong productivity effects from organizational innovations, and from a combination of process, product and organizational innovations. ICT investment is also an important driver of innovation in both manufacturing and services.

The studies therefore tend to support the hypothesis of ICT as GPT, and the complementarity hypothesis between ICT and different kinds of intangibles. Though the literature on this subject is still limited, because of the scarcity of data from national accounting sources, it tends to finally validate the strong ability of ICT to spawn innovation in a wide range of firms and sectors.

5.2.2.3 Summary of empirical literature key findings

To sum up, we find the following elements of confirmation of the GPT features of ICT investments, and on the role played by OI investments in the literature :

1. For ICT and OI investments, as for R&D, “*excess*” returns and specific spillover effects that may be sources of endogenous growth.
2. For ICT, studies tend to estimate that output and TFP elasticities are close to those generally admitted for R&D, that are centered around 0.08. For OI, the number of empirical studies remains very limited, and it is only very recently that time series based on national accounting methods became available, notably with the development of the INTAN-INVEST database. OI investments are diverse things but in our definition they are limited to two categories: firms specific human capital (investments in training) and investments in software. The available studies conclude, nevertheless, that there are also “*excess*” returns associated with OI investments, notably in training, while the strong contribution of software to productivity growth was already recognized in growth accounting literature⁵ and by the econometric studies that often include software, as well as hardware, in their definition of ICT capital.
3. Lastly, the most recent studies tend to support the idea that there are strong complementarities between investments in ICT and investments in different kinds of intangible assets. There is also empirical evidence of complementarities between, on the one hand, ICT and OI investments and, on the other hand, R&D investments, but they appear to be more indirect and to result from networks effects and from the strategic complementarities existing between the different production sectors.

5.3 The new frame introduced in Nemesis

This section presents the new conceptual frame that was introduced in NEMESIS to represent innovation, which includes both the new growth theories *à la Romer* (1990, [284]) and the concept of GPT introduced by Bresnahan and Trajtenberg (1995 [43]). The motivations for this extension were summarized in the preceding section, showing that ICT have been a major driver of economic growth

⁵1 But the growth accounting literature focuses on the contribution of capital deepening to labor productivity growth and doesn't “explain” the growth of TFP *per se*.

and productivity since the mid 90s, and play a major role in the innovation process in most production sectors today. The survey of these studies, presented in the preceding section, tends to confirm that ICT have the main properties of a GPT ([222]) that we summed up as “*pervasiveness*”, “*improvement*”, and “*ability to spawn innovation*”, that make a GPT an engine of growth. The main idea in the new modeling developments is the belief that detailed simulation models, such as NEMESIS, are very appropriate tools to grasp and model the interactions described above between the producers and users, as well as between users of a GPT such as ICT. We propose, for modeling these interactions, original methodologies that represent both the knowledge and network spillovers resulting from different innovative activities, as well as the strategic complementarities mentioned above. The various externalities are, until now, poorly represented in the applied literature, and structural modeling using NEMESIS may bring an important complement to grasp complex interactions between sectors, notably for the purpose of R&I policy analysis.

5.3.1 General outline: from Romer to Bresnahan & Trajtenberg

The new frame for modeling innovation in NEMESIS consists of two main points. The first point takes into account innovation inputs that are broader than R&D in the innovation function of the sectors. The first additional innovation input is related to investments in ICT, and the second one is related to investments that we grouped above under the name of Other Intangibles⁶ (OI). The second point is an explicit modeling of the knowledge externalities related to each category of innovation inputs: R&D, ICT and OI, using original methodologies developed in the context of the FP7 research projects DEMETER and SIMPATIC.

5.3.1.1 A three dimensional innovation function

Now at at sectorial and country level, a straightforward way to integrate the role played by investments in ICT and in intangible complementary assets, is to consider that innovation in a sector (i), in a country (c), at a time (t), A_{cit} , is a constant returns to scale combination (the function $G(\cdot)$ hereafter) of three

⁶The reasons of this limitation of OI to Software and Formation; while Corrado *et al.* (2012 [74]) propose other categories (Architectural and design, New financial products, Mineral exploration and Artistic originals, Advertising and market research, Organisational capital); is that these latter tend globally to be more sector specific, and *a priori* are not important sources of inter-sectoral knowledge externalities. They consequently don't seem to fit well in our proposed modeling, but should be developed in future works to include them. The exception is Organizational capital, but the measure used by Corrado *et al.* (2012 [74]) - a share of managers' working hours - implied too heavy double accounting problems for retaining it in our work at this stage. On the contrary, Software and Formation investments are both recognized potential sources of externalities, that are well-identified in accounting data.

sub-innovations, that we denote as the “innovation components”:

$$A_{cit} = G (AR_{cit}, AT_{cit}, AI_{cit}), \quad (5.3.1)$$

where $A_{j_{cit}}$, $j = R, T, I$, are the innovation components related respectively to R&D, ICT and OI investments. We also model them with constant returns to scale technologies G_j , with $j = R, T, I$:

$$A_{j_{cit}} = G_j \left(KNOW_{j_{cit}}, \frac{j_{cit}}{Y_{cit}} \right), \quad (5.3.2)$$

These are positive functions of the knowledge externalities, $KNOW_{j_{cit}}$, relative to the use of innovation component j , and to the investment rate in the innovation component j : $\frac{j_{cit}}{Y_{cit}}$. The underlying idea in this last formulation, is that, for a given innovation component, the impact of the knowledge available to a sector on its innovation performance, is a positive function of its knowledge absorption capability, that is proportional to its investment rate in the specific asset: R&D, ICT or OI⁷. But the ability to absorb external knowledge must be also closely related to the proximity between firms, sectors and countries in the technology field, that we will develop later. The functions G_j can be specified, like in the previous version of the NEMESIS model (Brécard *et al.* 2006 [40]) presented in the chapter 4, where only R&D knowledge externalities are present:

$$A_{j_{cit}} = SC_{A_{j_{ci}}} \cdot KNOW_{j_{cit}}^{\lambda_{j_{ci}} \cdot \frac{j_{cit}}{Y_{cit}}}, \quad (5.3.3)$$

with $SC_{A_{j_{ci}}}$ a scale factor and λ_j , a positive parameter.

Taking equation (5.3.3) in growth rates, and assuming that the intensity of the input is constant in the long term, we obtain:

$$\hat{A}_{j_{cit}} = \lambda_{j_{ci}} \cdot \frac{j_{cit}}{Y_{cit}} \cdot KN\hat{O}W_{j_{cit}}, \quad (5.3.4)$$

and if we furthermore consider that knowledge externalities grow in the long term at a rate that is conditioned by external factors, such as the growth rate of population n , we thus have:

⁷The idea that external knowledge needs an absorptive capacity by the firm that receives it to transfer it into produce or process innovations is quite old and goes back to the seminal works of Cohen and Levinthal (1999, [64]).

$$\hat{A}j_{cit} = \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot n, \quad (5.3.5)$$

which gives a formulation for the evolution of the innovation component, j , that is between the semi-endogenous and the fully endogenous growth approaches, as already discussed in chapter 4.

Concerning the specification of the function $G(\cdot)$, we use nested CES functions, showing the complementarity existing between the three innovation components underlying the GPT concept. We can use:

$$A_{cit} = SC_{Aci} \cdot \left[\delta_{ARci}^{1+\rho_{Aci}} \cdot AR_{cit}^{-\rho_{Aci}} + \delta_{ATci}^{1+\rho_{Aci}} \cdot AT_{cit}^{-\rho_{Aci}} + \delta_{AIci}^{1+\rho_{Aci}} \cdot AI_{cit}^{-\rho_{Aci}} \right] \quad (5.3.6)$$

with SC_{Aci} a scale parameter, δ_{ARci} , δ_{ATci} and δ_{AIci} the distribution parameters and $\sigma_{Aci} = \frac{1}{1+\rho_{Aci}}$, the substitution elasticity between AR_{cit} , AT_{cit} and AI_{cit} .

The growth rate of innovations in the long term is consequently equal to:

$$\hat{A}_{cit} = \sum_j \varepsilon_{Aj_{cit}}^A \cdot \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot n, \quad (5.3.7)$$

with $\varepsilon_{Aj_{cit}}^A$, the elasticity of innovation with respect to the innovation component j , given by equation 5.3.34 *infra*. It therefore depends positively both on the growth rate of population and on the investment rates in the different innovation inputs.

5.3.1.2 Modeling of knowledge externalities

Concerning knowledge variables, $KNOWj_{cit}$, we model them as weighted sums of the stocks of assets⁸ (R&D, ICT or OI) belonging to all sectors and countries, by using the methodologies developed in the DEMETER and SIMPATIC projects, that present the advantage of measuring these externalities simultaneously in the intra-sectorial and in the international dimensions.

For R&D, the knowledge variable of the sector i in country c , $KNOWR_{cit}$, is defined as the sum of R&D capital stocks, $SR_{p,s,t-\Delta}$, from all countries/sectors (p, s), weighted by a coefficient of diffusion,

⁸The depreciation rates used are identical to Corrado *et al.* (2013): 15 % for R&D, 0.315 for ICT, 0.315 for Software and 0.4 for Training.

$\Psi_{p,s \rightarrow c,i}$, reflecting the relative propensity of the knowledge from a sector s , in country p , to be useful for innovation in sector i , in country c . We also consider that the R&D investments start producing knowledge after a delay Δ that we fix at two years.

$$KNOWR_{c,i,t} = \sum_{p,s} \Psi_{p,s \rightarrow c,i} \times SR_{p,s,t-\Delta} \quad (5.3.8)$$

We apply the same methodology to the ICT capital and to OI capital where the coefficient of diffusion is $\Theta_{p,s \rightarrow c,i}$ with,

for ICT capital:

$$KNOWT_{c,i,t} = \sum_{p,s} \Theta_{p,s \rightarrow c,i} \times ST_{p,s,t-\Delta} \quad (5.3.9)$$

and, for OI capital:

$$KNOWI_{c,i,t} = \sum_{p,s} \Theta_{p,s \rightarrow c,i} \times SI_{p,s,t-\Delta} \quad (5.3.10)$$

Public investments in R&D ($PIRD$) are taken into account and allocated to the various sectors using a grand fathering distribution⁹ and are considered productive after a longer lag than private R&D (4 years) so that $SR_{p,s,t} = (1 - \delta_{RD}) SR_{p,s,t-1} + IRD_{p,s,t} + \alpha_{p,s} PIRD_{p,t-2}$.

The diffusion parameters are calibrated using matrices based on patent citations between sectors and countries¹⁰. These matrices combine the citations between patents allocated by technology class and country, with the OECD concordance table (Johnson, 2002 [176]), to allocate these citations between sectors. Two methods can be adopted for the sectorial allocation: *(i)* one considering the sectors that produce the technology related to the patents (Industry Of Manufacturing, IOM thereafter) and *(ii)* the other considering the sectors that use this technology (Sector Of Use, SOU thereafter). The assumptions underlying the choice of the method to build these matrices were the following:

1. Sectors manufacturing a technology are sectors that spent R&D investments for this technology. They receive knowledge externalities coming from inventions by sectors that manufacture other technologies. From this perspective, patents allocated to Industry Of Manufacturing (IOM) reflect the output of the R&D efforts made by these sectors. The citations between patents

⁹i.e. they are proportional to the share of each sector in the overall business R&D expenditure.

¹⁰These matrices were developed by Meijers and Verspagen (2010, [240]) in the framework of the DEMETER project, see also Belderbos and Mohnen (2013 [26])

belonging to IOM may be considered as indicators of the knowledge externalities between IOM sectors.

2. The externalities related to the use of ICT and OI may reflect network externalities. Assuming that ICT and OI are inputs of organizational changes, they may also reflect the diffusion of organizational innovations (the development of a new online distribution channel for instance). As these types of invention are not patentable, it is not possible to use the same matrix as for R&D externalities. Nevertheless, these inventions are assumed to be strongly related to the use of technical innovations. So, it can be assumed that sectors using the same type of technologies should have similar production methods and therefore similar organizational strategies. Their intangible investments, as well as their ICT investments, may be related. Matrices defined by patent citations allocated by SOU are thus retained. According to this approach, the more two SOU cite each other, the more they use the same technology and, therefore, the more one sector can benefit from the innovations of the other in the same field.

Concerning the calculus of spread parameters, several methodological issues have to be considered:

Regarding externalities in R&D, the degree to which the knowledge produced in sector s in country p , potentially useful for the sector i in the country c , is measured with the help of patent citations between IOM. This means that the more patents belonging to (c, i) have a propensity to cite patents belonging to (p, s) , the more an innovation in (p, s) is potentially useful for (c, i) and, therefore, the more R&D engaged in (p, s) may generate knowledge externalities to (c, i) .

The raw number of citations between (c, i) and (p, s) must be controlled by the size in terms of patents of these two sectors. The more patents filed by (p, s) , the more patents from (p, s) will be cited by patents from (c, i) . Then, the more patents are filed in (c, i) , the more patents from (c, i) will cite patents from (p, s) , for a given propensity to cite. Therefore raw citations do not only reflect the propensity of an innovation in (p, s) to affect the innovation capacity of (c, i) , but also the intensity of the innovation activity of these two sectors, already taken into account by R&D investments. Thus, in order to avoid double counting, the raw number of citations is controlled by the number of patents belonging to these two sectors. In addition, this coefficient is normalized such that the sum $\sum_{p,s} \Psi_{p,s \rightarrow c,i} = 1$. The spread¹¹ parameter from (p, s) to (c, i) is then defined as:

¹¹We prefer to call it a “spread parameter” instead of a “diffusion parameter” as it reflects the diffusion of the knowledge through space and not through time.

$$\begin{aligned}
 \Psi_{p,s \rightarrow c,i} &= \frac{C_{c,i \rightarrow p,s}^{IOM-IOM}}{N_{c,i}^{IOM} \times N_{p,s}^{IOM}} / \left(\sum_{u,v} \frac{C_{c,i \rightarrow u,v}^{IOM-IOM}}{N_{c,i}^{IOM} \times N_{u,v}^{IOM}} \right) \\
 &= \frac{C_{c,i \rightarrow p,s}^{IOM-IOM}}{N_{p,s}^{IOM}} / \left(\sum_{u,v} \frac{C_{c,i \rightarrow u,v}^{IOM-IOM}}{N_{u,v}^{IOM}} \right)
 \end{aligned} \tag{5.3.11}$$

This final coefficient represents the propensity of an innovation from (p, s) to be used to invent in sector (c, i) . In this way, knowledge is supposed to be non exclusive and non-rival¹².

For externalities in ICT and OI, the spread parameters are built with matrices where patents are allocated across sectors according to there Sector Of Use (SOU):

$$\begin{aligned}
 \Theta_{p,s \rightarrow c,i} &= \frac{C_{c,i \rightarrow p,s}^{SOU-SOU}}{N_{c,i}^{SOU} \times N_{p,s}^{SOU}} / \left(\sum_{u,v} \frac{C_{c,i \rightarrow u,v}^{SOU-SOU}}{N_{c,i}^{SOU} \times N_{u,v}^{SOU}} \right) \\
 &= \frac{C_{c,i \rightarrow p,s}^{SOU-SOU}}{N_{p,s}^{SOU}} / \left(\sum_{u,v} \frac{C_{c,i \rightarrow u,v}^{SOU-SOU}}{N_{u,v}^{SOU}} \right)
 \end{aligned} \tag{5.3.12}$$

Note that if the spread parameters are identical for ICT and OI, the resulting knowledge matrices are different since these parameters weight the respective stocks of ICT and OI.

5.3.1.3 Sectorial inter-dependencies: interactions through knowledge externalities and enabling technologies

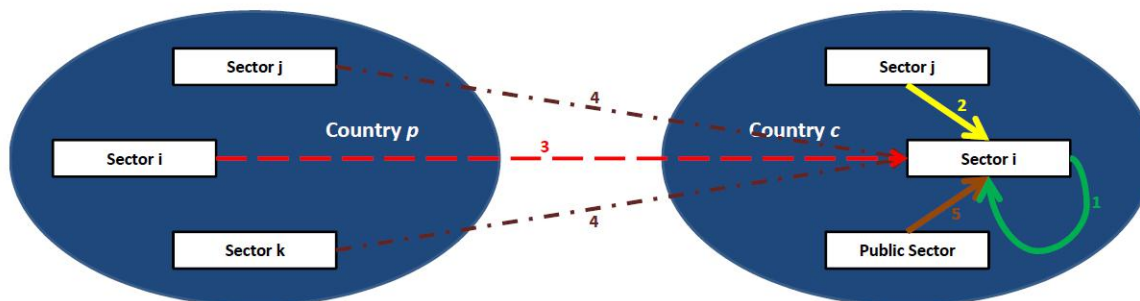
The previous section 5.3.1.2 has described the innovation process at stake inside each sector in the new frame that we developed for modeling innovation in NEMESIS. In particular, it highlighted the fact that knowledge created by other sectors, is also taken into account in the knowledge stock usable by the considered sector, and it also explained how these knowledge externalities act in the innovation process.

The graph 5.3.1 outlines these interactions and, according to this chart, we can distinguish five origins of knowledge externalities for a sector i in a country c : (1) Intra-sectorial national (first arrow), *i.e.* the knowledge resulting from previous innovations achieved in the sector in the same country; (2) Inter-sectorial national (second arrow), that are the externalities coming from other sectors in the same country; (3) Intra-sectorial international (third arrow) and (4) Inter-sectorial international (fourth arrow), that are the externalities arising from foreign countries and, finally, (5) for R&D, externalities coming from public research. Furthermore, in this new frame, knowledge flows were extended from

¹²This is not the case if we use a measure, sometimes used in the literature, $C_{c,i \rightarrow p,s} / C_{p,s}$ where $C_{p,s}$ is the total number of citations received by (p,s)

R&D to knowledge externalities related to organizational features of innovation, linked to the use of ICT and investments in complementary OI assets.

Figure 5.3.1 – Knowledge flows



Source: Fourgeyrollas et al., 2015 [120]

But this new modeling frame introduces new types of sectorial inter-dependencies related to the innovation process, that stem from the GPT properties of ICT. Theoretically, ICT-producing sectors and ICT-using sectors¹³ are “strategic complements” as defined by Bulow *et al.* (1985 [49]): there exists a virtuous circle where advances in GPT lead to inventions in their applications in the user sectors, which, in turn, increase the return of further development in GPT by the producer sectors.

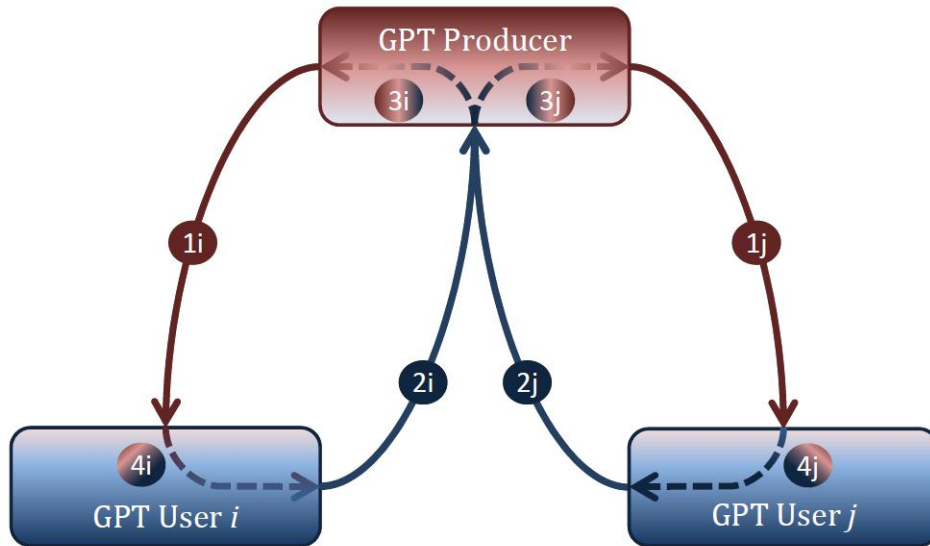
These complementarities between the two types of sectors were described by Bresnahan (2003 [44]) and Bresnahan and Trajtenberg (1995 [43]) as the two categories of positive externalities that we have schematized in graph 5.3.2:

1. Two vertical externalities (between “producers” and “users”): innovations by “producers” increase the returns from innovation for “users” (arrows 1*i* and 1*j*). Conversely, the more “users” there are, the higher the incentive for “producers” to invest in R&D and improve their technologies (arrows 2*i* and 2*j*). These externalities reflect innovation complementarities and a problem of appropriability that runs both ways. It corresponds, theoretically, to a “bilateral moral hazard problem” (Holmstrom, 1982 [164] and Tirole, 1994 [311]).
2. An horizontal externality between “user” sectors, that links the interests of the agents adopting the technology: when there are more “users”, their demand increases leading to a higher level

¹³In NEMESIS the latter are principally the Electronic Goods and Office Machine sectors, though all economic sectors use ICT.

of investment in the GPT which in return lowers innovation costs in the “user” sectors. This externality creates a ripple effect in ICT adoption and reflects the generality of the purpose of ICT. In figure 5.3.2, these externalities are depicted by the paths given by arrows $2i - 3j - 1j$ for the externalities generated by the innovations of i on user j and reciprocally, the externalities generated by the innovations of j on user i by arrows $2j - 3i - 1i$.

Figure 5.3.2 – GPT mechanisms



Source: Le Hir [205] and Fourgeyrollas et al., 2015 [120]

We now turn to the practical implementation of this new frame in the NEMESIS model.

5.3.2 Implementation in NEMESIS

The implementation of the new theoretical frame just described for modeling innovation in NEMESIS is not straightforward and the specifications introduced in the model must also take into account other important features of the innovation process. They concern mainly the distinct impacts that process and product innovations have on the economic performance of firms, and on employment.

5.3.2.1 Introduction of process and product innovations

This new frame in NEMESIS retains the formulations proposed above with the innovation components (equation 5.3.3), the innovations (equations 5.3.6), and the different knowledge variables (equations

5.3.8 to 5.3.10) and spread parameters (equations 5.3.11 and 5.3.12).

Furthermore, like in chapter 4, it introduces the innovations into the production functions of the sectors, as a CES combination with the set of ordinary production factors, X_t :

$$Y_{cit} = C_{ci} \cdot \left[\delta_{Aci}^{1+\rho_Y ci} \cdot A_{cit-1}^{-\rho_Y} + \delta_{Xci}^{1+\rho_Y ci} \cdot X_{cit}^{-\rho_Y ci} \right]^{-\frac{1}{\rho_Y ci}} \quad (5.3.13)$$

with, C , a scale parameter, δ_A the share parameter for A theoretically representing the cost of innovation services in the total cost of producing Y , for the base year of NEMESIS (2005), δ_X , the share parameter for X with by definition $\delta_X = 1 - \delta_A$, and ρ_y , the parameter defining the partial substitution elasticity between innovation services and X as $\sigma_Y = \frac{1}{1+\rho_Y}$. The set of other production factors, X , that regroup, energy, other intermediate consumption, non ICT physical capital, low and high skilled labor, are modeled with the CES nesting shown in chapter 4. The impact of innovations on productivity is consequently Hicks neutral, but this assumption could be challenged in future works. Furthermore, innovations are supposed to produce their services after one year, like physical capital inputs.

But besides their effects on productivity enhancement, innovations also have an impact through the production of new varieties of goods and services, and quality improvement of existing ones. Therefore we consider in NEMESIS that in every type of sectors, investments in innovation inputs produce two simultaneous effects:

- Process innovations that decrease ex-ante the use of X_{cit} per unit of output, Y_{cit} , with an elasticity of α_{cit} ;
- Product innovations that increase ex-ante, the quality of products, with an elasticity α'_{cit} , but without decreasing the use of X_{cit} per unit of output, Y_{cit} . It results from the assumption that customers have a “*taste for novelty*” that makes demand increase whenever the “*quality*” adjusted price of products, $\frac{P_{Y_{cit}}}{Q_{cit}}$, decreases, with $P_{Y_{cit}}$, the unit production price of output, and $Q_{cit} = A_{cit-1}^{\alpha'_{cit}}$, the “*quality*” index of output.

The result is that firms invest in innovation until the marginal expected impact on sales, $\frac{\partial(P_{Y_{cit+1}} \cdot Y_{cit+1})}{\partial A_{cit}}$, plus the marginal impact of the total cost of using X_{cit} , $-\frac{\partial(TC_{X_{cit+1}})}{\partial A_{cit}}$, is equal to the marginal cost of investing in innovation services, $w_{A_{cit}}$, with the following expression for the user cost of innovation services, $w_{A_{cit}}$:

$$w_{A_{cit}} = P_{A_{cit}} \cdot (1 + a), \quad (5.3.14)$$

where a is the actualization rate.

Therefore using the dual of the production function (equation 5.3.13), the firm will choose optimal A_{cit} such as:

$$A_{cit}^* = SC_{Y_{ci}}^{\sigma_{Y_{ci}}-1} \cdot \delta_{A_{ci}} \cdot \left(\frac{\tilde{w}_{A_{cit}}}{P_{Y_{cit+1}}} \right)^{-\sigma_{Y_{ci}}} \cdot Y_{cit+1}, \quad (5.3.15)$$

where $\tilde{w}_{A_{cit}} = w_{A_{cit}} - E_{cit} \left(\alpha'_{cit+1} \cdot \frac{Y_{cit+1}}{A_{cit}} \cdot P_{Y_{cit+1}} \right)$, is the user cost of innovations, corrected¹⁴ from the ex-ante marginal impact of investing in innovation on expected sales, $E_t(\cdot)$.

The demand for innovation components is then determined as the set of three inputs that minimize the user cost of the innovations. Using the dual of equation 5.3.6:

$$A_{j_{cit}}^* = SC_{A_{ci}}^{\sigma_{A_{ci}}-1} \cdot \delta_{A_{j_{ci}}} \cdot \left(\frac{P_{A_{j_{cit}}}}{P_{A_{cit}}} \right)^{-\sigma_{A_{ci}}} \cdot A_{cit}^*, \quad (5.3.16)$$

with $j = R, T, I$, $P_{A_{cit}} = [\delta_{AR_{ci}} \cdot P_{AR_{cit}}^{1-\sigma_{A_{ci}}} + \delta_{AT_{ci}} \cdot P_{AT_{cit}}^{1-\sigma_{A_{ci}}} + \delta_{AI_{ci}} \cdot P_{AI_{cit}}^{1-\sigma_{A_{ci}}}]^{\frac{1}{\sigma_{A_{ci}}-1}}$, and where $P_{A_{j_{cit}}}$, the unit cost of the innovation components, will be defined later.

With the optimal demand for the innovation components, the optimal investments in R&D, ICT and OI, j_{cit}^* , can be obtained by inverting equation 5.3.3, for $j = R, T, I$, and by using the following semi-log form:

$$j_{cit}^* = \left[\frac{\ln(A_{j_{cit}}^*) - \ln(SC_{A_{j_{ci}}})}{\ln(KNOW_{j_{ci}})} \right] \cdot \frac{Y_{cit}}{\lambda_{j_{ci}}} \quad (5.3.17)$$

which gives, by replacing $A_{j_{cit}}^*$ by its expression (equation 5.3.16):

$$j_{cit}^* = \left[\frac{\ln(C_{ci}) - \sigma_{A_{ci}} \cdot \ln \left(\frac{P_{A_{j_{cit}}}}{P_{A_{cit}}} \right) + \ln(A_{cit}^*)}{\ln(KNOW_{j_{ci}})} \right] \cdot \frac{Y_{cit}}{\lambda_{j_{ci}}}, \quad (5.3.18)$$

with C_{ci} a positive constant.

Lastly, the user cost of innovation components is obtained by using the optimality conditions for

¹⁴This expression is used as we cannot analytically solve the optimal demand for innovation services, for the reason that they influence at the same time total factor productivity and demand. It can be solved numerically in NEMESIS or proxied as $\tilde{w}_{A_{cit}} = (1 - sp_{ci}) \cdot w_{A_{cit}}$, with $sp_{ci} = \frac{\frac{\partial(P_{Y_{cit+1}} \cdot Y_{cit+1})}{\partial A_{cit}}}{\left(\frac{\partial(P_{Y_{cit+1}} \cdot Y_{cit+1})}{\partial A_{cit}} - \frac{\partial(TC_{X_{cit+1}})}{\partial A_{cit}} \right)}$ the “share” of product innovations that is fixed to 33% in NEMESIS (see sub-section 5.3.2.2 below).

innovation activities that imply, for $j = R, T, I$:

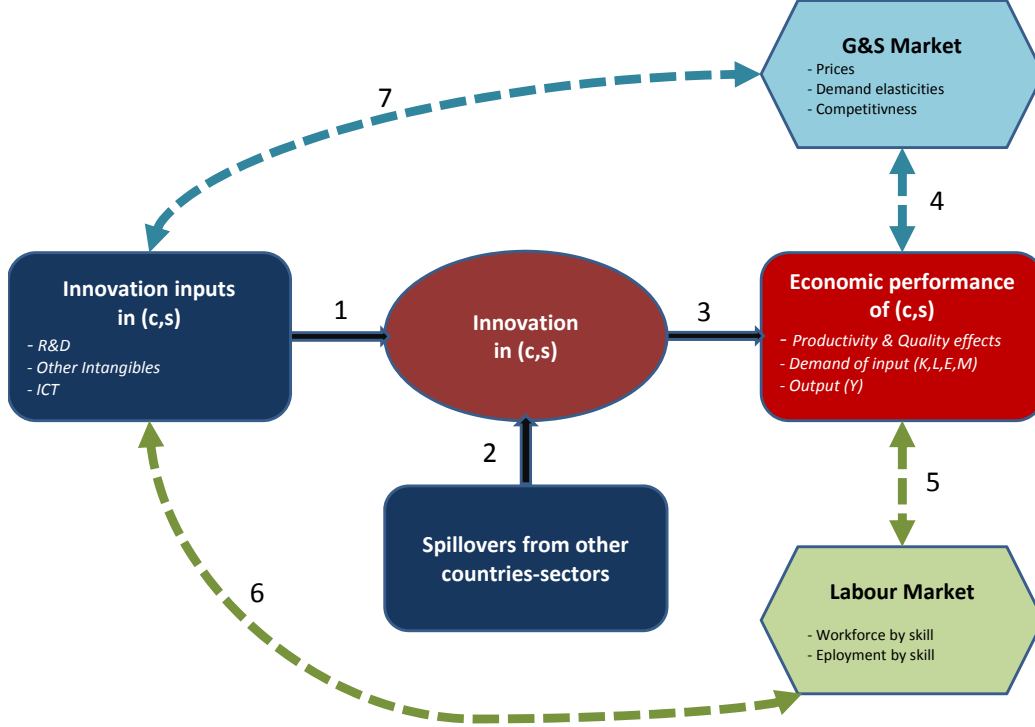
$$\frac{\partial (P_{Aj_{cit}} \cdot J_{cit})}{\partial j_{cit}} = P_{j_{cit}}, \quad (5.3.19)$$

from which it results:

$$P_{Aj_{cit}} = P_{j_{cit}} \cdot \frac{Y_{cit}}{\lambda_{ci}} \cdot \frac{1}{Aj_{cit}^*} \quad (5.3.20)$$

The way this new frame to represent innovation in NEMESIS acts throughout the whole economic system is summed-up by the figure 5.3.3. The innovations in each sector in each country result from the investments in the three innovation components, as explained above, and, in addition to the own investments of the country-sector (c,s), investments in innovation inputs by other country-sectors generate spillovers and increase the ability of the considered (c,s) to innovate. The combination of these two elements - the own expenditures in innovation inputs and the spillovers - generates innovations (arrows 1 and 2) which lead (3) to an increase in the economic performance of the sector in terms of productivity and quality, and then to an increase in demand through the reduction of the quality adjusted price of products. The interaction between the innovation performance of the sector and the Goods and Services market (5) determines the output of the sector. And the interaction between the labor market and both activities of production and of innovation (5 and 6) leads to the determination of employment. Finally, innovations by the producers of enabling technology (ICT producers in our case), lead to a decrease in the price of this technology, which, in return, diminishes the cost of innovation inputs (arrows 5 and 7) and thus the cost of innovation for the users of the enabling technology.

Figure 5.3.3 – Innovation and economic feedbacks



Source: Le Hir [205] and Fourgeyrollas et al., 2015 [120]

5.3.2.2 Endogenous growth properties

This sub-section analyzes the endogenous properties resulting from the new innovation mechanisms introduced in the model more closely. For that, let's start by expressing the long term growth rate of sectorial output in NEMESIS, by differentiating the equation for sectorial output (equation 5.3.13) in natural logarithms with respect to time, we obtain:

$$\frac{d \ln(Y_{cit})}{dt} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \frac{d \ln(A_{cit})}{dt} + \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{d \ln(X_{cit})}{dt} \quad (5.3.21)$$

with:

$$\varepsilon_{A_{cit}}^{Y_{cit}} = \frac{\partial \ln(Y_{cit})}{\partial \ln(A_{cit})} = SCY_{ci}^{-\rho Y_{ci}} \cdot \delta A_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{Y_{cit}}{A_{cit}}\right)^{\rho Y_{ci}} \quad (5.3.22)$$

the elasticity of sectorial output with respect to innovations services (A), and

$$\varepsilon_X^{Y_{cit}} = \frac{\partial \ln(Y_{cit})}{\partial \ln(X_{cit})} = SCY_{ci}^{-\rho Y_{ci}} \cdot \delta X_{ci}^{1+\rho Y_{ci}} \cdot \left(\frac{Y_{cit}}{X_{cit}}\right)^{\rho Y_{ci}} \quad (5.3.23)$$

the elasticity of sectorial output with respect to the bundle of traditional production inputs (X).

The long term growth of sectorial output therefore split into two components:

1. An endogenous one, driven by the growth of innovation services:

$$\frac{d \ln(Y_{cit}^A)}{dt} = \varepsilon_{A_{cit}}^{Y_{cit}} \cdot \frac{d \ln(A_{cit})}{dt} \quad (5.3.24)$$

2. and an exogenous one, driven by the growth of traditional production factors:

$$\frac{d \ln(Y_{cit}^E)}{dt} = \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{d \ln(X_{cit})}{dt} \quad (5.3.25)$$

so we have:

$$\frac{d \ln(Y_{cit})}{dt} = \frac{d \ln(Y_{cit}^A)}{dt} + \frac{d \ln(Y_{cit}^E)}{dt} \quad (5.3.26)$$

We see from equation (5.3.26) that the endogenous growth rate of sectorial output can be assimilated to a “pure” TFP effect, as the literature generally does. We have therefore:

$$\frac{d \ln(Y_{cit}^A)}{dt} = \frac{d \ln(TFP_{cit})}{dt} = \frac{d \ln(Y_{cit})}{dt} - \frac{d \ln(Y_{cit}^E)}{dt} \quad (5.3.27)$$

or equivalently:

$$\frac{d \ln(TFP_{cit})}{dt} = \frac{d \ln(Y_{cit})}{dt} - \varepsilon_{X_{cit}}^{Y_{cit}} \cdot \frac{d \ln(X_{cit})}{dt} \quad (5.3.28)$$

In this first interpretation, the problem studied in the empirical literature is the measurement of the extent of TFP growth, that is to say the gap between the growth of output and the growth of traditional production factors, that can be explained by investments in innovation inputs, such as R&D, ICT and OI, and their related knowledge externalities.

In reality, the TFP indexes that can be computed from economic data, sum-up many different effects, and the joint influence of many mechanisms, as we will detail now.

We can, using our modeling, alternatively define the “TFP effect” as *minus* the elasticity of the demand of production inputs with respect to innovations, that is from equation 5.3.13 by keeping Y_{cit}

constant:

$$\alpha_{cit} = -\frac{\partial \ln(X_{cit})}{\partial \ln(A_{cit})} = \frac{\varepsilon_A^{Y_{cit}}}{\varepsilon_X^{Y_{cit}}} \quad (5.3.29)$$

We see that this “TFP effect” is different from the definition given by equation 5.3.28 and must be interpreted this time as a measure of the deformation of the set of production possibilities provoked by the growth of innovation in time, for a fixed level of output.

A second effect of innovations in NEMESIS is linked to the increase of the demand provoked by the gradual improvement of the characteristics of the products (from equation E23 in table 5.3.2). This “Quality effect” is defined as:

$$\frac{d \ln(Q_{cit})}{dt} = \alpha'_{cit} \cdot \frac{d \ln(A_{cit})}{dt} \quad (5.3.30)$$

In each sector, the “quality” of output is supposed to evolve in time proportionally (with a coefficient m_{ci}) to the “TFP effect”, such as we have:

$$\alpha'_{cit} = m_{ci} \cdot \alpha_{cit} \quad (5.3.31)$$

In NEMESIS these two distinct innovations (or *innovations effects*) act on the sectorial output of firms through the price elasticity of demand, $\varepsilon_{cit}^D < 0$:

1. Process innovations will reduce the unit cost of the firms with an elasticity α_{cit} and then increase demand with the elasticity: $-\varepsilon_{cit}^D \cdot \alpha_{cit}$.
2. Product innovations will increase demand with the elasticity: $-\varepsilon_{cit}^D \cdot \alpha'_{cit}$

As at equilibrium, the level of output equates the level of demand, the growth rate of output provoked by the growth of innovations, i.e., the “endogenous” growth rate of output, $\frac{d \ln(Y_{cit}^A)}{dt}$, will then be equal to:

$$\frac{d \ln(Y_{cit}^A)}{dt} = \left(-\varepsilon_{cit}^D \cdot \alpha_{cit} - \varepsilon_{cit}^D \cdot \alpha'_{cit} \right) \cdot \frac{d \ln(A_{cit})}{dt} = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \frac{d \ln(A_{cit})}{dt} \quad (5.3.32)$$

This “endogenous” growth rate of sectorial output does not just measure a pure TFP effect, like in equation 5.3.29, and it is the resultant of three combined effects:

1. A TFP effect through the elasticity α_{cit} ;
2. A quality effect through the elasticity $\alpha'_{cit} = m_{ci} \cdot \alpha_{cit}$;
3. A demand effect through the elasticity ε_{cit}^D .

It can be split again to represent the distinct contributions of the three innovation components on long term endogenous growth rate. To do this, we start by differentiating the equation 5.3.6 that provides the mathematical expression of innovation services, with respect to time

$$\frac{d \ln(A_{cit})}{dt} = \sum_j \varepsilon_{Aj_{cit}}^A \cdot \frac{d \ln(Aj_{cit})}{dt}, \quad j = RD, ICT, OI \quad (5.3.33)$$

with:

$$\varepsilon_{Aj_{cit}}^A = SC A_{ci}^{-\rho A_{ci}} \cdot \delta A_{ci}^{1+\rho A_{ci}} \cdot \left(\frac{A_{cit}}{Aj_{cit}} \right)^{\rho A_{ci}} \quad (5.3.34)$$

By assuming that the investment rates of innovation assets (in % of production) at sectorial level are constant in the long term, the growth rates of innovation components can themselves be further split from equation 5.3.3 as:

$$\frac{d \ln(Aj_{cit})}{dt} = \lambda_{j_{ci}} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{d \ln(KNOW j_{cit})}{dt} \quad (5.3.35)$$

We then get by substituting 5.3.35 in 5.3.33:

$$\frac{d \ln(A_{cit})}{dt} = \sum_j \varepsilon_{Aj_{cit}}^A \cdot \lambda_{j_{ci}} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{d \ln(KNOW j_{cit})}{dt}, \quad j = RD, ICT, OI \quad (5.3.36)$$

and by substituting 5.3.36 in 5.3.32:

$$\frac{d \ln(Y_{cit}^A)}{dt} = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{Aj_{cit}}^A \cdot \lambda_{j_{ci}} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{d \ln(KNOW j_{cit})}{dt}, \quad j = RD, ICT, OI \quad (5.3.37)$$

A few general comments on the implications of the last equation 5.3.37 on the properties of the endogenous growth (of output) in NEMESIS can be useful at this stage:

- Firstly, there is no endogenous growth at sectorial or macro levels in NEMESIS without growth in knowledge externalities. From a theoretical perspective, this property re-links the modeling

of innovations in NEMESIS to the semi-endogenous growth literature where the ultimate source of growth is the size of the R&D sector (here at world level) and of knowledge externalities that expand with the growth of population, as explained in chapter 4. This property of the semi-endogenous growth models was simply extended in NEMESIS to sources of externalities other than R&D. The consequence is that the endogenous growth rate in NEMESIS is strongly dependent on the assumptions made on the growth of knowledge externalities in the reference scenario of the model. We generally assume in the reference scenario, that goes up to 2050, that the investment rates of the innovation assets stay constant in the medium (say 2025) to long term (2050), and that knowledge growth is proportional to the growth of world GDP.

- Secondly, as we already assumed in chapter 4, the approach used in NEMESIS conforms to the *Schumpeterian* or *Fully endogenous II* approach initiated by Aghion and Howitt (1998, [4]), Dinopoulos and Thompson (1998, [101]) and Peretto (1998, [266]): the long term endogenous growth rate is an increasing function of the investment rates in innovation assets, that can be influenced by policy instruments.
- Thirdly, from the two first points, the way the policies aiming to raise innovation input intensities, such as subsidies, will act on the long term endogenous growth rate, split into two effects:
 1. the rise of the ability of firms to exploit existing knowledge (*intensity effect*)
 2. and the creation of new knowledge that increases the intrinsic productivity of innovation inputs (*knowledge effect*) .

As it is shown in section 5.5, these two effects can play very different roles depending on the sector, the country or the innovation input considered.

5.3.2.3 Overview of the innovation mechanisms/equations introduced into NEMESIS

The set of equations implemented in NEMESIS to represent innovation at sectorial level is finally summed-up in the table 5.3.1. It includes 23 equations¹⁵ that split in four categories of equations or variables:

1. Behavioral equations or decision variables, that result from the maximization of expected inter-temporal profit by firms;

¹⁵These are the equations at the core of the innovation module but others exist like research employment described as three categories (Researchers/engineers, Technicians, Other), etc.

2. Update equations of state variables, that result from past decisions and past evolutions, such as the accumulation of knowledge variables that influence the productivity of the different innovative inputs;
3. Equations that calculate the “*price*” of innovation components and innovation services, that result from the resolution of the system of equations;
4. The “*Transmission*” equations, that link the innovation decisions (1) to the production decisions of the firms by the TFP effects of innovations on the demand of production inputs X and (2) to the demands for goods and services by firms’ customers, that are influenced by the relative improvements in product characteristics (product innovations).

As displayed in table 5.3.2, out of the 23 equations there are only 7 behavioral equations¹⁶ and variables that can be directly affected by the implementation of policy measures in the model.

If we sum-up over all countries and sectors, we finally get a set of $23 \times 28 \times 29 = 18676$ equations at sectorial level, to which one must add an epilogue for the calculus of key indicators, *e.g.* national innovation input intensities, etc.

To complete the overview of these innovation mechanisms in NEMESIS, table 5.3.1 shows the analytical expression of the equations introduced in the model. For simplicity, we only provide the optimal expression for the decision variables¹⁷, corresponding to the variables with a star. The index j is for $j = RD, ICT, OI$. Time lags were removed also, as well as expectation operators to simplify the presentation, but these are active in the model and make its dynamic.

¹⁶In fact for the representative firm in the sector, the “true control variables” are only the vector of demands for innovation inputs (RD^*, ICT^*, OI^*).

¹⁷The final expression for decision variables includes the impact of adjustments costs and various delays.

Table 5.3.1 – Sum-up of the equations intervening at the “core” of the innovation module of NEMESIS

Type of Equation/ Variable	Name/Description	Nb of Equations/ Variables of this Type	Comments
<i>Behavioural Equations/ Decision Variables</i>	<p>RD^*, ICT^*, OI^*: Optimal demand for innovation inputs</p> <p>$ARD^*, AICT^*, AOI^*$: Optimal demand for innovation components</p> <p>A^*: Optimal demand for innovation services</p>	7	Results from firms' optimal decisions for maximizing inter-temporal profit. There is no market for innovations that are produced “in-house” in NEMESIS
<i>Update Equations/ State variables</i>	<p>$ARD, AICT, AOI$: Actual levels of innovation components</p> <p>A: Actual level of innovation services</p> <p>$SRD, SICT, SOI$: Actual stocks of innovation assets</p> <p>$KNOWRD, KNOWICT, KNOWOI$: Actual stocks of knowledge</p>	10	Result from past decisions that represent the actual values used by the firms at time t
<p><i>Prices</i></p> <p><i>Transmission equations</i></p>	<p>$PARD, PAICT, PAOI$: Price of innovation components</p> <p>PA: Price of innovation services</p> <p>X: Demand of production inputs (TFP effect)</p> <p>Q: Product innovations (Quality effect)</p>	<p>4</p> <p>2</p>	<p>Analytical expression results from the resolution of the system of equations</p> <p>The demand for the bundle of production inputs X makes the link between the innovation and production decisions of the firms in NEMESIS from the TFP impacts of innovations.</p> <p>They are a fixed proportion in NEMESIS (the quality effect is proportional to the TFP effect)</p>

Table 5.3.2 – Analytical expression of the equations at the core of the innovation module of NEMESIS

Variable description	Equation	Nb
Optimal demands for innovation inputs	$j_{cit}^* = \left[\frac{\ln(C_{ci}) - \sigma_{A_{ci}} \cdot \ln\left(\frac{PA_{j_{cit}}}{PA_{cit}}\right) + \ln(A_{cit}^*)}{\ln(KNOW_{j_{cit}})} \right] \cdot \frac{Y_{cit}}{\lambda_{j_{cit}}}$, with C_{ci} a positive constant	(E1-E3)
Optimal demand for innovation components	$A_{j_{cit}}^* = SCA_{ci}^{\sigma_{A_{ci}}} \cdot \delta A_{j_{cit}} \cdot \left(\frac{PA_{j_{cit}}}{PA_{cit}}\right)^{-\sigma_{A_{ci}}} \cdot A_{cit}^*$	(E4-E6)
Optimal demand for innovation services	$A_{cit}^* = SCY_{ci}^{\sigma_{Y_{ci}}} \cdot \delta A_{ci} \cdot \left(\frac{\tilde{\omega} A_{cit}}{PY_{cit}}\right)^{-\sigma_{Y_{ci}}} \cdot Y_{cit}$, with $\tilde{\omega} A_{cit}$ the user cost of innovation services	(E7)
Actual levels of innovation components	$A_{j_{cit}} = SCA_{j_{cit}} \cdot KNOW_{j_{cit}}^{\lambda_{j_{cit}}} \cdot Y_{cit}^{j_{cit}}$	(E8-E10)
Actual level of innovation services	$A_{cit} = SCA_{ci} \cdot \left(\delta ARD_{ci}^{1+\rho_{A_{ci}}} \cdot ARD_{cit}^{-\rho_{A_{ci}}} + \delta AICT_{ci}^{1+\rho_{A_{ci}}} \cdot AICT_{cit}^{-\rho_{A_{ci}}} + \delta OI_{ci}^{1+\rho_{A_{ci}}} \cdot AOI_{cit}^{-\rho_{A_{ci}}} \right)^{\frac{1}{\rho_{A_{ci}}}}$	(E11)
Actual stocks of innovation assets	For R&D stocks: $SRD_{pst} = (1 - \delta_{RD}) \cdot SRD_{pst-1} + RD_{pst} + \alpha_{ps} \cdot PIRD_{pt-2}$ For ICT and OI stocks: $Sj_{pst} = (1 - \delta_j) \cdot Sj_{pst-1} + j_{pst}$	(E12) (E13-14)
Actual stocks of knowledge	For R&D: $KNOWRD_{cit} = \sum_{p,s} \Phi RD_{p,s \rightarrow c,i} \times SRD_{p,s,t-\Delta}$ For ICT: $KNOWICT_{cit} = \sum_{p,s} \Theta ICT_{p,s \rightarrow c,i} \times SICT_{p,s,t-\Delta}$ For OI: $KNOWOI_{cit} = \sum_{p,s} \Theta OI_{p,s \rightarrow c,i} \times SOI_{p,s,t-\Delta}$	(E15) (E16) (E17)
Price of innovation components	$PA_{j_{cit}} = \frac{Pj_{cit}}{Aj_{cit}} \cdot \frac{Y_{cit}}{\lambda_{ci}}$, with Pj_{cit} the prices of innovation inputs	(E18-E20)
Price of innovation services	$PA_{cit} = \left[\delta ARD_{ci} \cdot PARD_{cit}^{1-\sigma_{A_{ci}}} + \delta AICT_{ci} \cdot PAICT_{cit}^{1-\sigma_{A_{ci}}} + \delta AOI_{ci} \cdot PAOI_{cit}^{1-\sigma_{A_{ci}}} \right]^{\frac{1}{1-\sigma_{A_{ci}}}}$	(E21)
Demand of production inputs	$X_{cit} = Y_{cit} \cdot A_{cit}^{\alpha_{cit}}$	(E22)
Product innovations	$Q_{cit} = A_{cit}^{\alpha'_{cit}}$	(E23)

5.4 Calibration of the new NEMESIS innovation module

This section 5.4 presents the general methodology used to calibrate the innovation module of NEMESIS. The main objective of the calibration is to ensure that the simulations of the NEMESIS model provide

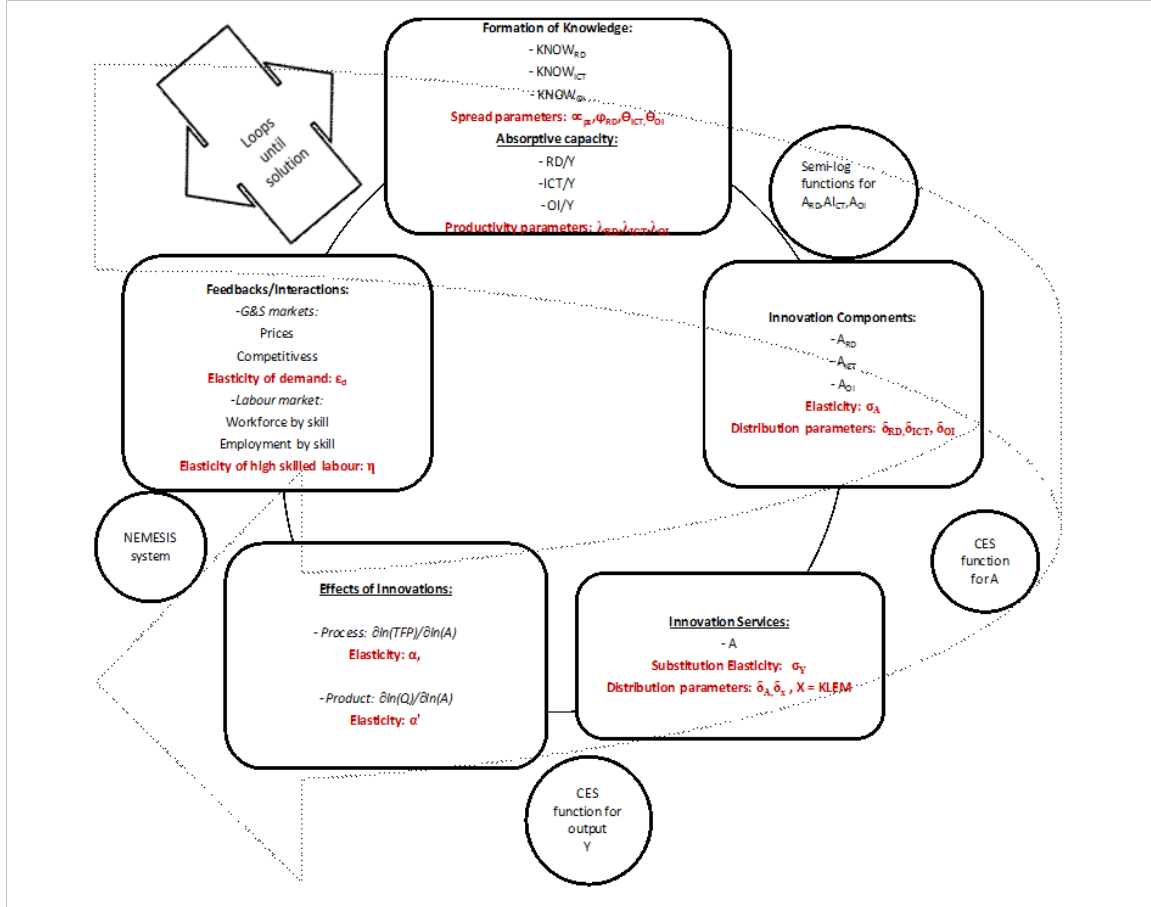
results in phase with the theoretical and empirical literature on central elements for policy assessment of R&D and innovation policies. These elements, that can be analyzed at sectorial, national or EU-28 levels, are notably:

1. The “economic performance” of innovations, e.g., what is the elasticity of sectoral output or of GDP to innovations?
2. The employment effects of innovations. How strong? Positive or negative?
3. The distinct impacts of product and process innovations on economic performance and employment.
4. The strength and impacts of knowledge externalities, notably from public and private research. Do they crowd-in/-out private R&D investments and to what extent?
5. What are the impacts of knowledge externalities relative to ICT and OI?
6. What are the distinct impacts of R&D, ICT and OI assets on economic performance and employment?
7. What are the implications of innovation component complementarities? Do ICT investments need complementary investments in OI to produce positive impacts on employment and growth as ICT in GPT literature suggests? And do they also crowd-in R&D investment from network effects as the theoretical literature would suggest?

5.4.1 The innovation chain

Calibration is not very straightforward as most of the effects we want to measure using the model, to compare with the findings of economic literature on innovations, are indirect, and pass through a chain of mechanisms and inter-dependencies as the figure 5.4.1 below shows. This figure provides a simplified algorithmic representation of the way the innovation mechanisms introduced in the model act in NEMESIS. Starting from the top of the figure and rotating clockwise, each rectangular box contains a set of inputs, including different categories of variables or mechanisms described in bold and underlined typefaces, and different categories of parameters indicated in bold and red typefaces. On the right, these inputs are combined with functions, indicated in the different circles that calculate outputs that are also the inputs of the next rectangular box, together with new sets of parameters and elasticities, and so on.

Figure 5.4.1 – The chain of effects to calibration from the sectorial level to interactions within the NEMESIS system



The four first rectangular boxes and the first three categories of functions in the circles, synthesize the innovation mechanisms introduced at sectorial level that are summed-up in 5.3.2. All the variables, parameters, elasticities and functions represented by these first boxes and circles, are defined at a sectorial level, and represent calibrations that must be done for every country and every sector cited in NEMESIS. On the contrary, the last circle and the last box of the left side, describe the interactions and feedbacks that occur, when solving the model¹⁸, between the innovation mechanisms introduced at a sectorial level, just described, and the macroeconomic forces coming, for example, from the impact of innovations on households' disposable income and consumption choices, on external competitiveness and firms' export performance, on labor demand through skill sets and on wages evolution, that will

¹⁸In fact the solver classes and solves the equations in order of increasing degree of interdependencies, or "endogeneity", and initiates loops until a stable solution is found.

retro-act on innovation input productivity and on their private and social rates of return.

For convenience and to clearly distinguish the effects calibrated at a sectorial level, before the interactions and macroeconomic feedbacks, and the effects that are measured after the solving of the model, we call the latter *ex-post* effects, and the former, *ex-ante* effects.

Having now made this important distinction between *ex-ante* and *ex-post* effects, the fundamental question is what type of effects the literature, for example the literature on R&D and productivity, calculates, and how can its main findings be compared with the results of the simulation experiments achieved using this model?

Our position on this question, that is under discussion, is that by definition data from national accounting sources, on which a large part of empirical studies are based, are themselves *ex-post*, and the effects and elasticities measured by these studies are also *ex-post*. The same is true for the relationships measured in an increasing number of studies using more qualitative data, such as the successive editions of the CIS.

Therefore ultimately the simulation results of the model must be compared with the main findings in economic literature, and section 5.5 presents (1) the results of analytical simulations achieved with the default setting used for the different parameters and elasticities, and (2) the sensitivity of these results to changes in the values used for key parameters settings. To do this, first we have to justify our methodological choices to calibrate the innovation chain illustrated by figure 5.4.1 above.

5.4.2 Calibration of innovation chain

The equation 5.3.37 provides a reduced form expression of the endogenous growth mechanisms that were introduced in NEMESIS at a sectorial level, illustrated by figure 5.4.1. It is a synthetic representation of the impact that firms may expect *ex-ante* from their investments in innovation inputs, on the long term growth rate of their output. We see that whenever the expected growth of knowledge externalities, that are supposed to be exogenous for firms, is positive, the expected impact of investment in innovation inputs on firms' output will always be positive. *Ex-post*, as all countries and all production sectors innovate and invest in innovation inputs, the final impact of innovation on sectorial output is *a priori* undetermined, and will differ from the *ex-ante* effects measured by equation 5.3.37.

These discrepancies between the *ex-ante* and *ex-post* effects stem, as explained above, from the interactions and feedbacks that occur, when solving the model, between the innovation mechanisms introduced at the sectorial level and the resulting macroeconomic forces. Innovations will modify the

relative competitiveness of the different EU countries and affect the consumption choices of households, that will be re-oriented towards the goods and services with the better price to quality ratios. The TFP effects of innovations may also have a mitigated impact on output and employment in sectors that principally produce production goods, as in the intermediate sectors, because of the productivity gains made in the other sectors in the economy. Some countries may also encounter inflationary pressures if their labor market is initially too tight, especially for high skills needed for innovation activities, as this will reduce the benefits expected from investing in innovation.

Therefore, while the *ex-ante* effects of innovations, at the level of a sector, are always positive, even if they are contrasted depending on whether the sector is a good innovator or not, the *ex-post* effect measured after all the macroeconomic feedbacks, will give much more contrasted results in terms of production and employment impacts, for the different sectors and countries.

So using our calibration methodology, our presentation will encounter the different terms of equation 5.3.37 above from right to left, and will follow the figure 5.4.1 from top to bottom, moving clockwise.

The first term, the the growth of knowledge variables relative to the different innovation asset, $\frac{dln(KNOW_{jcit})}{dt}$, are computed following the equations E15 to E17 in table 5.3.2. Their growth is conditioned by the growth of innovation asset stocks at inter-sectorial and international levels, that are weighted by the “spread” parameters $\Phi RD_{p,s \rightarrow c,i}$, $\Phi ICT_{p,s \rightarrow c,i}$ and $\Phi OI_{p,s \rightarrow c,i}$ for respectively R&D, ICT and OI knowledge externalities. For R&D, there are additional spread parameters, $\alpha_{ps} = \frac{RD_{pst0}}{RD_{pt0}}$, that measure the knowledge transfers from public research towards private firms. In the the model, the geographical scope of knowledge externalities is limited to EU-28 countries, plus US and Japan, excluding some important R&D new players such as South Korea and China. In the reference scenario of NEMESIS, where we assume that the sectorial investment rates in innovation assets as a % of production or turnover are constant in the medium to long term (between 2020 and 2050), these knowledge externalities grow in average at about 1.5 % per year and roughly follow the growth rate of GDP, with discrepancies depending on the country or the sector.

The second term is $\lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{dln(KNOW_{jcit})}{dt}$, that, from equation 5.3.35, measures the growth of innovation components, $\frac{dA_{jcit}}{dt}$, in the reference scenario of NEMESIS. These innovation components are “work” variables in our modeling framework. They cannot be measured by statistics and the solution we retained, in NEMESIS, is to make the assumption that they grow at the same rate as the knowledge externalities to which they are related in the reference scenario of the model. We then have

by assumption:

$$\frac{d \ln (A_{jcit})}{dt} = \frac{d \ln (KNOW_{jcit})}{dt}, j = RD, ICI, OI \quad (5.4.1)$$

which can be obtained by assuming, the “productivity” parameters, λ_{jci} , in equation 5.3.35 are all equal to 1, and also by normalizing the innovation input intensities, $\frac{j_{cit}}{Y_{cit}}$, in this equation, by their value in the reference scenario of the model, $\frac{j_{cit}^{Ref}}{Y_{cit}^{Ref}}$, as the ratio $\frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}^{Ref}}{Y_{cit}^{Ref}}}$ is equal to one. With these assumptions, the equation 5.3.37 becomes therefore:

$$\frac{d \ln (Y_{cit}^A)}{dt} = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{Ajcit}^A \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}^{Ref}}{Y_{cit}^{Ref}}} \cdot \frac{d \ln (KNOW_{jcit})}{dt}, \lambda_{jci} = 1, j = RD, ICT, OI \quad (5.4.2)$$

The third term, from the preceding assumptions expresses (from equation 5.4.2) $\varepsilon_{Ajcit}^A \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}^{Ref}}{Y_{cit}^{Ref}}} \cdot \frac{d \ln (KNOW_{jcit})}{dt}$, and measures the contribution of the growth of the distinct sources of knowledge - or equivalently, from equation 5.4.1, that of the growth of the different innovation components - on the growth of innovation services, $\frac{dA_{cit}}{dt}$. We see that, in the reference scenario of the model, by normalizing at 1 the investment rates of innovation assets in equation 5.3.37 and by setting the values of parameters λ_{jci} to 1, that these contributions are measured by the elasticities ε_{Ajcit}^A , defined by equation 5.3.34. In the case of Cobb-Douglas, when the substitution possibilities between the three innovation components are perfect ($\sigma_{A_{ci}} = \frac{1}{1 + \rho_{A_{ci}}} = 1$ and $\rho_{A_{ci}} = 0$), these elasticities are equal to the value of the distribution parameters of innovation components in the production function of innovation services (equation E11 in table 5.3.2):

$$\varepsilon_{Ajcit}^A = \delta A_{jci}, j = RD, ICT, OI \quad (5.4.3)$$

In our calibration the default setting for the substitution elasticity between innovation components 0.25, is far from the Cobb-Douglas case. In section 5.5, a sensitivity analysis on the value of this elasticity, from the perfect complementarity case ($\sigma_{A_{ci}} = 0$) to the perfect substitutability case ($\sigma_{A_{ci}} = 1$), shows that the assumptions retained on the value of this elasticity does not affect the simulation results, and that consequently the values of the elasticity ε_{Ajcit}^A remain strongly related to the values of the distribution parameters of innovation components, whatever the value of the substitution elasticity $\sigma_{A_{ci}}$.

These distribution parameters are calibrated in NEMESIS so they reflect, in each sector, the share of the investment in innovation assets j , relative to the total investment in innovation assets in the sector. Furthermore the sum of the distribution shares equals one, for: $\sum_j \delta A_{jci} = 1$. The precise calibration methodology is as follows. We have:

$$\delta A_{jci} = \frac{\delta A_{jci}}{\sum_j \delta A_{jci}}, \quad j = RD, ICT, OI \quad (5.4.4)$$

with:

$$\delta A_{jci} = 0.5 \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{cit}} + 0.075 \cdot \left(1 - \frac{j_{cit}}{Y_{cit}}\right)}, \quad j = RD, ICT, OI \quad (5.4.5)$$

which also implies that $\sum_j \delta A_{jci} = 1$.

The links retained in NEMESIS between the values of the distribution parameters and the sectorial intensities of innovation assets are not strictly linear and are concave (homographic) functions of the input intensities in equation 5.4.5. We retained this solution in order to avoid “out-layer” problems which may occur in very intensive sectors with certain innovation inputs.

The fourth term, $\cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jci}}^A \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{cit}} + 0.075 \cdot \left(1 - \frac{j_{cit}}{Y_{cit}}\right)} \cdot \frac{d \ln(KNOW_{jci})}{dt}$ measures, the contribution of the growth of the different knowledge externalities and innovation components, to the “TFP” effect, with the introduction in the formula of the elasticity α_{cit} . This elasticity is defined by the equation 5.3.29, as the ratio $\alpha_{cit} = \frac{\varepsilon_{A_{cit}}^{Y_{cit}}}{\varepsilon_X^{Y_{cit}}}$. If the CES production function that combines the innovation services, A_{cit} , with the bundle of traditional production factors, X_{cit} , is a Cobb-Douglas ($\sigma_{Y_{ci}} = \frac{1}{1+\rho_{Y_{ci}}} = 1$ and $\rho_{Y_{ci}} = 0$), this last elasticity is equal to the ratio between the distribution parameters of innovation services and of the bundle of traditional production factors in equation 5.3.13:

$$\alpha_{cit} = \frac{\delta A_{ci}}{\delta X_{ci}} \quad (5.4.6)$$

This Cobb-Douglas assumption was used in the previous version of the model with only R&D, presented in chapter 4. In this new version of the model, we use it again: there are good reasons to suppose that process innovations are perfect substitutes for production inputs in the long term.

The parameters δA_{ci} are calibrated in NEMESIS as:

$$\delta A_{ci} = \sum_j \delta A_{jci}, \quad j = RD, ICT, OI \quad (5.4.7)$$

and they “reflect” the cost of innovation inputs within the total cost of producing the final output, Y_{cit} . We proceed like this because there are no other satisfactory proxies for measuring the cost of innovation services.

We also impose that the two distribution parameters sum to 1, so:

$$\delta X_{ci} = 1 - \delta A_{ci} \quad (5.4.8)$$

We also remark that as the parameters δA_{ci} “reflect” the cost of innovation inputs in % of the production cost in sector i in country c , that is about 4.3% on EU-28 average¹⁹, then the δX_{ci} parameters are on average close to one and the α_{cit} elasticities are themselves in average close to the value of δA_{ci} . Therefore, using our calibration strategy, the impact on sectorial TFP of the growth of the distinct knowledge externalities, $\frac{d \ln(KNOW_{jcit})}{dt}$, is, in the reference scenario of NEMESIS, close to proportional to the product of the two preceding elasticities: $\alpha_{cit} \cdot \varepsilon_{A_{jcit}}^A$, with $j = RD, ICI, OI$. If both the production functions of final output and of innovation services are Cobb-Douglas, the impact on TFP is finally close to:

$$\delta A_{jci} = \delta A_{ci} \cdot \delta A_{jci} = 0.5 \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{cit}} + 0.075 \cdot \left(1 - \frac{j_{cit}}{Y_{cit}}\right)}, \quad j = RD, ICI, OI \quad (5.4.9)$$

and is a positive, concave (homographic function) of the investment rate in the innovation input j .

The next term, $(1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jcit}}^A \cdot \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{d \ln(KNOW_{jcit})}{dt}$, introduces the role played by product innovations through the parameter m_{ci} , in the analysis. This parameter is the “proportionality” parameter, introduced in equation 5.3.31, that measures the relative strength of the productivity and quality effects of innovation services.

As we will discuss in section 5.5, the share of product innovations relative to the share of process innovations, equal to $sp_{ci} = \frac{m_{ci}}{(1+m_{ci})}$, is a crucial determinant of the output and employment impacts of

¹⁹It is, in our data, the EU-28 GDP “global” intensity for R& D (1.3%), ICT (0.95%) and OI (2.5%) investments by the private firms. If we include the investments by the public sector, we get a global intensity of 5.4% with 2% for R&D, 1.1% for ICT and 2.3% for OI.

innovations. We observe that the higher this share is, the higher the impact of innovations on sectorial output growth and on employment will be. Nevertheless it is very difficult to calculate, and it is only recently, with a few exceptions, that the empirical studies have begun to analyze the distinct impacts that the two categories of innovations have. These studies based on qualitative data tend to validate the way they act in NEMESIS. The share of product innovations was set at 33%. As many product innovations imply big reorganizations of production processes, process innovations should predominate. This value was finally retained as best value, using our analytical simulations, to accurately reproduce the mean impact of R&D investments on economic performance and on employment provided by the literature in the model.

The last term, $-\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{Aj_{cit}}^A \cdot \lambda_{jci} \cdot \frac{j_{cit}}{Y_{cit}} \cdot \frac{dln(KNOW_{j_{cit}})}{dt}$, includes the role played by the price elasticity of demand²⁰, ε_{cit}^D . We see that the endogenous growth rate of output provoked by innovations at sectorial level is proportional to the absolute value of this elasticity.

The price elasticity of demand is specific to sectors and countries and is an average calculated using demand from various origins: Export markets, households' and government's final consumption, investment and intermediate consumption. It is generally higher for industrial sectors with high export ratios, and for sectors that export very homogeneous goods (notably raw materials) compared to sectors producing highly differentiated products, that are generally also the most innovative. The value of this elasticity is generally inferior to 1 in macro-sectorial models. One main reason for this low elasticity found in empirical studies is that they do not generally use prices adjusted for quality. But if the demand rises with quality, and if prices and quality are positively correlated, it leads to downward biases for the estimated elasticity. This result also guided our choice to use price adjusted from quality in NEMESIS.

The table 5.4.1 finally sums-up our calibration methodology and gives the value retained for the key parameters intervening in the equations in the innovation module of NEMESIS. Our calibration strategy of course can be challenged and/or enhanced. In section 5.5 we provide illustrations of the impacts of changing the values of certain key parameters.

²⁰The price elasticity of demand results from the calibration and the econometric estimation of the NEMESIS model and cannot be imposed.

Table 5.4.1 – List of key parameters intervening in the innovation chain of NEMESIS

Parameters description	Parameter value or method calculation	Nb
<i>Spread parameters for knowledge externalities.</i> Measure the strength and direction of inter-sectoral and inter-national spillovers	$\Phi RD_{p,s \rightarrow c,i}$ $\Phi ICT_{p,s \rightarrow c,i}$ $\Phi OI_{p,s \rightarrow c,i}$ Calculation based of the methodologies developed in the context of DEMETER and SIMPATIC projects described in section 2.1.2	(P1-P3)
<i>Spread parameters for public R&D.</i> Measure the strength and direction of knowledge spillovers from public research	$\alpha_{ps} = \frac{RD_{ps,t0}}{RD_{pt0}}$ Grandfathering assumption: The more a sector invest in R&D (in % of total private R&D expenditure) the more it benefits from public research	(P4)
<i>Productivity parameters of innovation inputs.</i> Modify proportionally the impact of the different innovation input on the growth of innovations	λRD_{ci} λICT_{ci} λOI_{ci} The default setting in NEMESIS is 1	(P5-1 -3)
<i>Substitution elasticity between the different innovation components.</i> Measure the degree of complementarity between the innovation components in the production of innovation services	σA_{ci} The default setting is 0.25 in NEMESIS	(P6)
<i>Distribution parameters of innovation components.</i> Influence the elasticity of innovation services to the growth of innovation components and knowledge externalities	δRD_{ci} δICT_{ci} δOI_{ci} These are positively related to the cost of each innovation input within the total cost of producing innovation services in NEMESIS. They sum to 1 NEMESIS	(P7-P9)
<i>Substitution elasticity between innovation components and the bundle of traditional production factors in the equation for sectoral output.</i> The value of this elasticity is not critical in NEMESIS. Influences mainly the elasticity of innovation services to their user cost.	σY_d Set to 1 in NEMESIS	(P10)
<i>Distribution parameters of innovation services and of the bundle of traditional production factors</i> Influence the elasticity of sectoral output to the growth of innovation services	δA_{ci} δX_{ci} The parameter for innovation services is positively related to the cost of innovation inputs in the total production cost of output. The sum of the two parameters is set to 1 in NEMESIS	(P11-P12)
<i>Share of product innovations.</i> Influence positively the economic performance of innovations in terms of output growth and employment creation	sp_{ci} This average value of this share is 33% in NEMESIS	(P13)

5.4.3 Data used for calibration

The calibration of NEMESIS new innovation module uses historical data from different sources but it relies also on the “*Reference scenario*” developed for the I3U research project, that is a projection of the EU economy up to 2050, quantified using the NEMESIS model (see Le Mouél *et al.*, 2017, [?]).

For R&D, ICT and OI expenditure, the following data sources have been used:

- For R&D, there are two concepts for the sectorial allocation: either through “*main activities*” or “*product fields*”. The latter has been used in this study to build the database. The main sources are EUROSTAT ([116]), OECD STAN (ANBERD), and INTAN-INVEST (Corrado *et al.* 2012 [74]). When the data were not available from the “*product fields*” approach, a methodology to pass from “*main activities*” approach to “*product fields*” approach was used. This methodology was established with the help of databases covering both approaches.
- Data for ICT, including data on investments in Information Technologies (IT) and Communication Technologies (CT), were taken from the EU-KLEMS database (Timmer *et al.* 2017 [309]), which provides detailed sectorial data for the main European countries.
- Data on OI came from INTAN-INVEST (Corrado *et al.* 2012 [74]) which provides information for 10 sectors in 14 European countries for the period 1995-2010. A large range of intangible categories are available in this database (10, including R&D), but only “*Software*” and “*Training*” were used to build the IO variables.

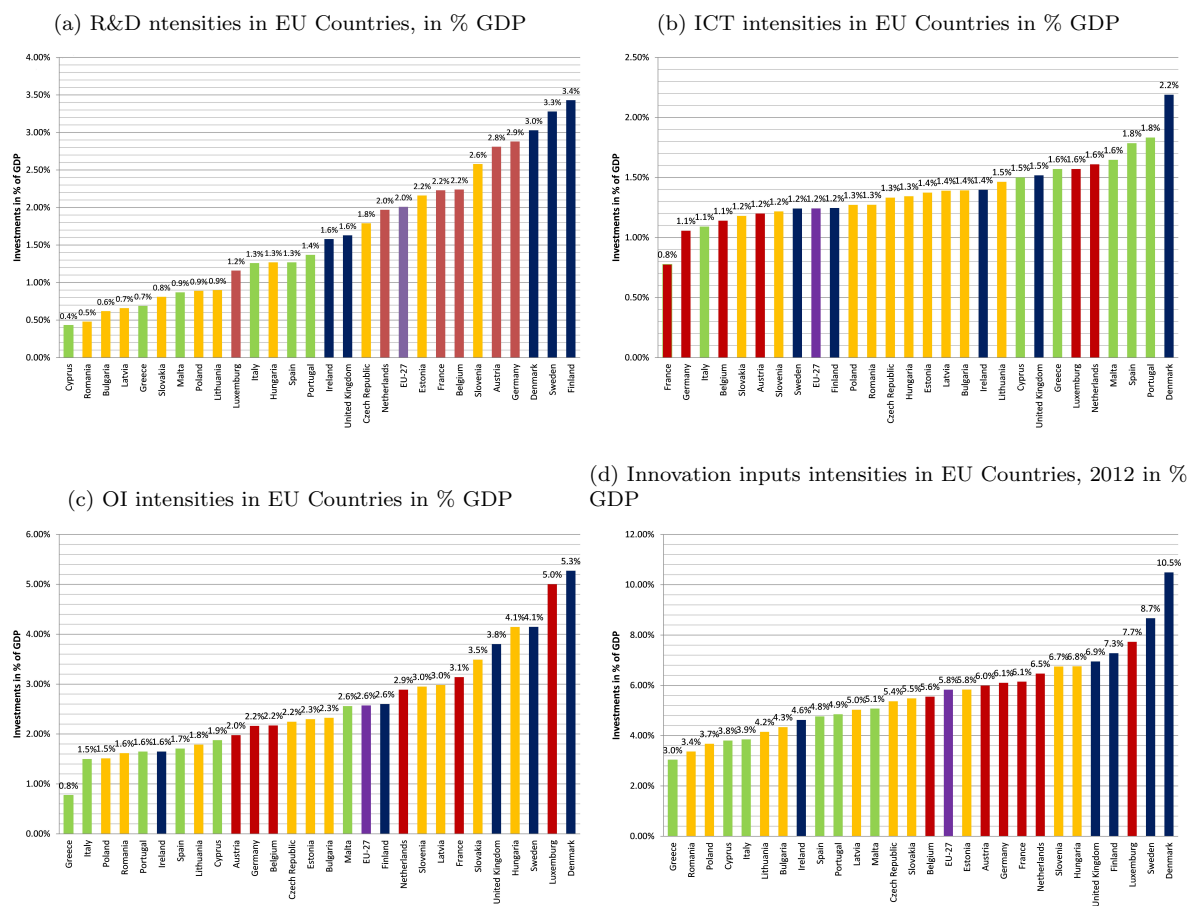
The geographical and sectorial coverage of the databases was generally narrower than that of the model, forcing us to build missing data. The adopted methodology was as follows:

- When the sectorial data were not detailed enough, we assumed that the intensity of the asset, in % of value-added, was identical, in every sub-sector, and equal to the intensity of the aggregated sector.
- When the data for a country were not available, we used the average sectorial intensity of the group of countries it belongs to, by using the 4 countries’ groups : Northern Countries, Central Europe, Southern Countries and Eastern Countries²¹.

²¹With respectively Northern countries: Denmark, Finland, Ireland, Sweden and the United Kingdom; Central Europe: Austria, Belgium, France, Germany, Luxembourg and the Netherlands; Southern countries: Cyprus, Greece, Italy, Malta, Portugal and Spain; Eastern countries are the remaining countries: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

The data covered the period 1995 to 2010. After 2010, the data were extrapolated up to 2050 by keeping R&D, ICT and OI intensities constant in % of value-added, in every sector and every country. Consequently, the projected aggregated intensity of R&D, ICT or OI could vary over time due a sectorial composition effect.

Figure 5.4.2 – Intensities in innovation inputs in % GDP, 2012



For these data for 2012, the figure (5.4.2a) shows that the average R&D intensity of the EU stays close to 2% of European GDP, a level only 15% higher than the 2000 intensity (1.8%), while the Barcelona objective, defined in 2002, strove to reach 3% in 2010. The EU and National Action Plans for R&I that were established did not deliver the expected positive impacts for boosting European Research, except for Germany, that increased its R&D intensity from 2.4% to 2.88% (and 2.92% in 2013), Austria with a rise from 1.89% to 2.81%, Portugal that rose from 0.72% to 1.36%, and, for example, Slovenia in Eastern Europe, that increased its R&D effort from 1.36% GDP in 2000 to 2.58%

in 2012. Despite the important progress accomplished by some countries of Eastern and Southern Europe, others have reduced their effort, and the figure (5.4.2a) confirms the East-West and North-South European divide shown by R. Veugelers (2014, [273]). Most of the countries belonging to these Eastern (in Yellow) and Southern (in Green) groups have an R&D effort well below the EU average, while most of the countries belonging to the Central (in Red) and Northern (in Blue) groups are situated above this EU average. This European divide also exists for investments in education and the share of high skilled labor (ISCEDs over 4) in the total labor force (see SIMPATIC deliverable D10.3 [122]). EU R&D investment intensity remained more or less stable for over a decade, indicating an innovative environment that is still weak compared to the performance of EU's main competitors, with R&D to GDP ratios in 2012 of 2.81 for USA, 3% in Japan, and China that doubled its intensity in 2012 (1.98%) compared to the 2000 level.

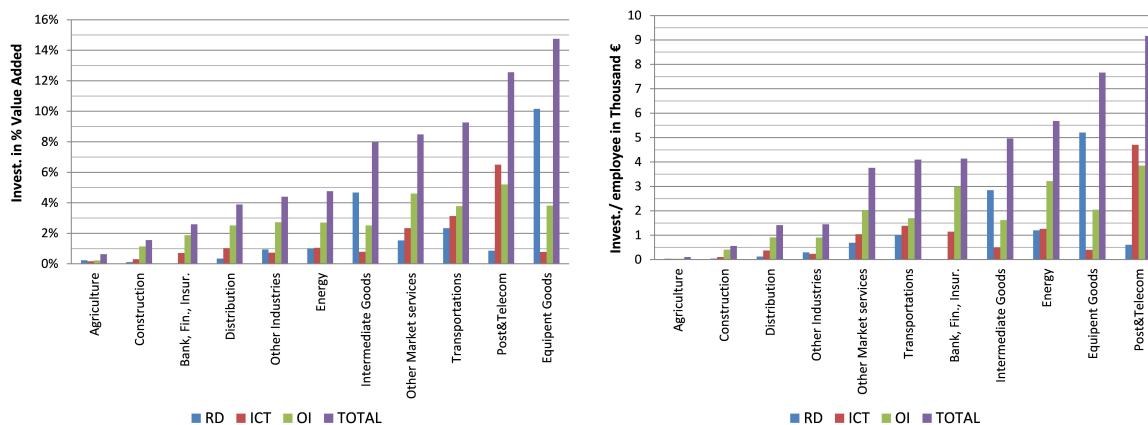
An important part of the American-European productivity gap, and notably the sluggish productivity growth in Service industries in Europe compared to the productivity revival observed in United States after 1995, can therefore be linked to under-investments in R&D by manufacturing industries, and in ICT and OI in service industries, especially after 2000 (B. Le Hir, 2012 [205]). At EU level, investments in ICT²² represent about half the amount spent on R&D and investments in OI are slightly superior to R&D spending (see respectively figures 5.4.2b and 5.4.2c). Taking all innovation inputs together, the European innovation divide is still apparent (see figure 5.4.2d), and is mainly attributable to under-investment in R&D inputs in most Eastern and Southern countries, and to a lesser extent to inequalities in OI investment. The average intensity is 5.83%, with a minimum value of 3.03% in Greece and a maximum of 10.49% in Denmark.

Extending innovation inputs from R&D only to ICT and OI investments therefore widens the scope of innovation policies that can be studied with NEMESIS. This development enriches the analysis not only in terms of the quantification of impacts but also in qualitative terms, allowing a better grasp of inclusiveness of innovation policies as the innovative inputs are larger or smaller depending on sectors and countries (see figures 5.4.3a and 5.4.3b).

²²Excluding software which is included in Other Intangibles

Figure 5.4.3 – Sectoral intensities in innovative inputs, 2012

(a) Sectoral investment in innovation Inputs / Value Added, (b) Sectoral investment in innovation Inputs / Employees, 2012



5.5 Analytical tests

This section 5.5 complements the presentation of the innovation mechanisms of NEMESIS with the first illustrations of its functioning. Analytical tests were performed with a threefold aim:

1. Identify, using sensitivity analysis, what the critical parameters in the innovation chain of NEMESIS in terms of economic impacts measured by the model are. For example, is the value retained for the parameters truly determinant for the calculation of the GDP and employment impacts after a rise in R&D expenditures? Or do the impacts calculated by the model differ only marginally for different values of the parameters?
2. Check the endogenous growth properties of the model. For example, does a rise in innovation input intensities (in % of production or GDP) change the long term growth rate of GDP in EU countries (and by how much) as the “Fully Endogenous Growth” approach used in NEMESIS would suggest?
3. What are the distinct characteristics of the different innovation inputs? For example, what “ripple” effect does the investment in one innovation input have on the two others? Is this ripple effect more important for ICT investments, as literature on ICT as GPT suggests that they need complementary investment in intangible investments, such as Software and Training, to become fully productive? Do the strategic complementarities between ICT users and producers play

role?: The more you invest in ICT, the more the ICT sectors should invest in R&D to develop their technologies, and, in return, the more the user sectors should invest in ICT whose price adjusted for quality decreases, ...

5.5.1 Protocol

There are infinite possibilities to implement these tests that may concern a specific country, specific sectors or groups of sectors, public or private investments, and that may be implemented using endogenous subsidies or from exogenous shocks on innovation inputs, etc.

The methodology retained here is to implement exogenous shocks of 0.5 GDP point, alternatively on private R&D, ICT or OI investments. The shocks are big ones if one considers that the average private EU-28 R&D intensity is about 1.3%, and that it is about 0.95% for ICT and 2.05% for OI investments. They are important enough to check the capacity of the model to accept big shocks, as these would imply, for example, a scenario based on the Barcelona 3% target for R&D.

The shocks introduced in the model are not realistic and only have an analytical aim. They were implemented in 2015, where in every EU(28) country, the intensity of the targeted innovation input was increased by 0.5 GDP point, compared to its value in the reference scenario of the model, and the 0.5 GDP point was maintained up to 2050. This may represent a very important shock for certain countries, that have very contrasted intensities, notably for private R&D: From 0.1 GDP point in Cyprus to 2.3 GDP point in Finland in 2012.

The shocks are introduced at sectorial level following the grandfathering principle, meaning that the % increase of the innovation input is, *ex-ante*, before the model simulation, identical in every sectors. Thus the change in intensity, compared to the reference scenario, was more important in sectors initially intensive in input.

Finally, whereas the shocks were introduced "*exogenously*" and not provoked by financial incentives, they were financed by the firms that integrally reported these additional costs in their market prices. This is again a non-realistic assumption as the firms may prefer, for example, to reduce their margins to maintain their price competitiveness in the short to medium term, before the arrival of innovations produce their full impacts in terms of TFP and quality effects.

Four sets of tests were implemented:

1. In the first set, we compare the distinct short term to long term impacts on GDP and employment

of targeting the rise of innovation inputs either on R&D, on ICT or on OI. We notably compare the ripple effects that the different innovation inputs have on the others.

2. In the second set, we perform a sensitivity analysis on the value of the substitution elasticity between the three innovation components, from the perfect complementarity case ($\sigma A_{ci} = 0$) to the perfect substitutability case ($\sigma A_{ci} = 1$). We examine how the ripple effects are modified by the value retained for this elasticity and the implication for the long term growth rate of GDP.
3. In the third set, we remove the ripple effects that one asset has on the two others, that are exogenized, and we focus on the “proper” impact of the distinct assets on the long term growth rate of GDP. We also look at the specific impacts of the different sources of knowledge externalities by removing alternatively intra-sectorial externalities (national and international), intra-sectorial externalities (national and international) or all externalities at the same time.
4. The fourth set examines the role played by product innovation relative to process innovation. In the reference scenario of the model and for the tests implemented in points 1 to 3 above, the share of product innovations was fixed at 33%, so there are 1.5 more process than product innovations. We then look at the impacts of decreasing or increasing product innovations in proportion of process innovations.

All these tests have a “normalized” increased of innovation assets of 0.5 GDP point in common. An increased investment in an innovation asset will modify the “*ex-ante*” endogenous growth rate of the sectors in the model, that were calibrated from equation 5.4.2 as:

$$\frac{d \ln(Y_{cit}^A)}{dt} = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jcit}}^A \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{Ref}}{Y_{Ref}}} \cdot \frac{d \ln(KNOW_{jcit})}{dt}, \quad \lambda_{jci} = 1, j = RD, ICI, OI, \quad (5.5.1)$$

This equation can be re-expressed, for convenience, in growth rates, so we have:

$$\widehat{Y_{cit}^A} = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jcit}}^A \cdot \lambda_{jci} \cdot \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{Ref}}{Y_{Ref}}} \cdot \widehat{KNOW}_{jcit}, \quad \lambda_{jci} = 1, j = RD, ICI, OI, \quad (5.5.2)$$

From equation 5.5.2, the “*ex-ante*” change in the long term output growth of the sector ($\widehat{\Delta Y_{cit}^A}$), provoked by the permanent increase in the intensity of innovation input j compared to its level in the reference scenario of the model, $\frac{\Delta \frac{j_{cit}}{Y_{cit}}}{\frac{j_{Ref}}{Y_{Ref}}}$, will be equal to :

$$\Delta \widehat{Y}_{cit}^A = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jcit}}^A \cdot \lambda_{jci} \cdot \frac{\Delta \frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{Ref}}} \cdot \widehat{KNOW}_{j_{cit}}, \quad \lambda_{jci} = 1, j = RD, ICI, OI, \quad (5.5.3)$$

We call this effect the “*intensity effect*”, as it is proportional to the % increase of the targeted input intensity compared to its level in the reference scenario of NEMESIS. This results from the increased capacity of the sector to absorb the growth of external knowledge, compared to the situation on the baseline.

Now, if all the sectors and EU countries increase their investment in innovation input j , this will also change the growth rate of knowledge externalities ($\Delta \widehat{KNOW}_{j_{cit}}$) in the scenario, compared to their growth rate in the reference scenario of the model.

It this latter case, which corresponds to the simulation experiments we present here, the “*ex-ante*” endogenous growth rate of the sector will be modified by a second effect that we call the “*knowledge spillovers effect*”. We will then have:

$$\Delta \widehat{Y}_{cit}^A = -\varepsilon_{cit}^D \cdot (1 + m_{ci}) \cdot \alpha_{cit} \cdot \sum_j \varepsilon_{A_{jcit}}^A \cdot \lambda_{jci} \cdot \left(\frac{\Delta \frac{j_{cit}}{Y_{Ref}}}{\frac{j_{cit}}{Y_{Ref}}} \cdot \widehat{KNOW}_{j_{cit}} + \frac{\frac{j_{cit}}{Y_{cit}}}{\frac{j_{cit}}{Y_{Ref}}} \cdot \Delta \widehat{KNOW}_{j_{cit}} \right), \quad \lambda_{jci} = 1, j = RD, ICI, OI. \quad (5.5.4)$$

This last effect (at the right in the brackets) is only transitory in our experiments, where the growth of knowledge externalities tends in long term to return to its level in the reference scenario. This illustrates the semi-endogenous growth properties of our modeling, while the “*intensity effect*” illustrates its “*fully endogenous growth*” properties, that continue to have effects in long term, as we will see.

But the reader must bear in mind that the “*ex-post*” effects of increasing the investments in innovation assets, in our simulation experiments, will differ from these “*ex-ante*” effects described above. As all sectors and countries increase their investments, the relative competitiveness of the sectors and countries will be modified. There will be, in addition to knowledge externalities, rent - or productivity - spillovers conveyed by the exchange of goods and services between sectors and countries. This will globally increase the positive impacts of innovations. Also, the ripple effects that one innovation asset has on two others will provoke changes in all innovation input intensities and externalities simultaneously, increasing the positive impacts. But negative indirect impacts will also occur, coming, for

example, from the fall in the demand for production inputs provoked by the increase of TFP, that will reduce activity, or the possible tensions on the labor market, we have already mentioned.

5.5.2 The distinct impacts of innovation inputs with pulling effects

For this first set of analytical tests (see table 5.5.1), all the mechanisms introduced in the model are active, and parameters are all on their default setting. The aim is to illustrate the distinct impacts of a 0.5 GDP point exogenous increase on either private R&D (T1605), ICT (T2605) or OI (T3605) investments.

We will first focus on the comparison between the short term and long term impacts of the alternative shocks introduced in the model on the EU GDP. There are at least two ways to analyze the impacts on GDP. The first, as displayed on figure 5.5.1 below, is to examine the % deviation of the GDP compared to its level in the reference scenario in the model, at different points in time. The first statement is that whatever increased input is, there are three periods of effects in time.

Table 5.5.1 – The first set of analytical tests

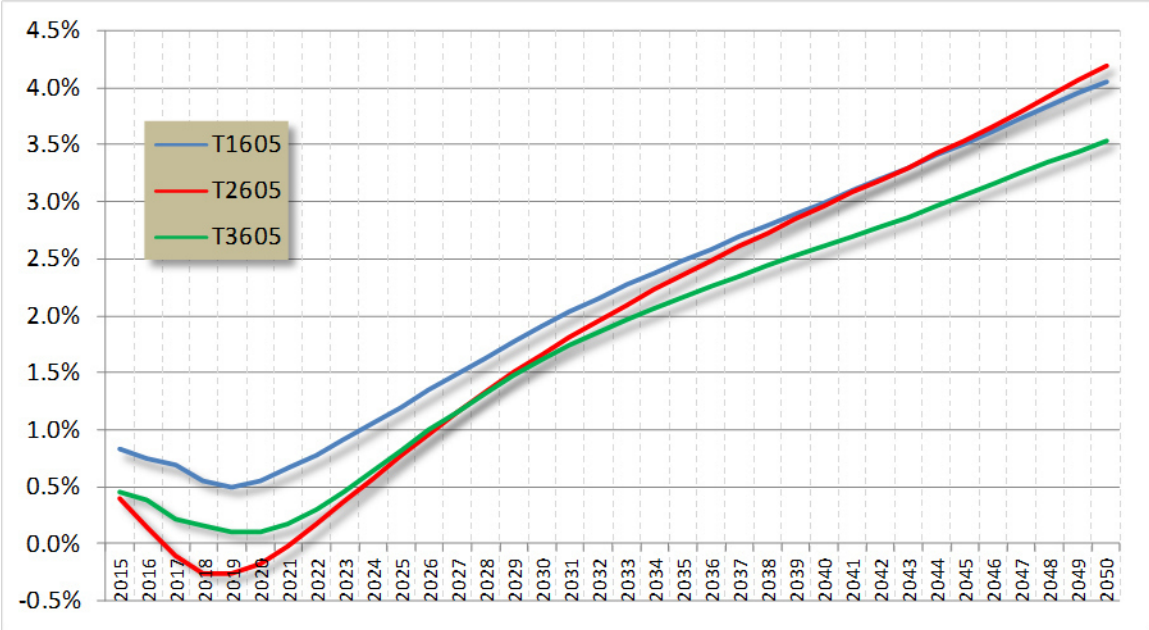
Scenario name	General setting			Exogenous increase in GDP points of		
	Knowledge spillovers	Share of product innovations	Substitution elasticity between innovation components	RD	ICT	OI
T1605 - RD	YES	33%	0.25	0.5	0	0
T2605 - ICT	YES	33%	0.25	0	0.5	0
T3605 - OI	YES	33%	0.25	0	0	0.5

We call the first period, that goes from the first year of the shock (2015) up to 2019-2020, the “*maturation*” or “*investment*” phase. During this initial period, investments do not create any important new process and product innovations, because of the “*maturation*” delays introduced into the model. The main impacts on GDP come from the “*multiplier*” effect of investments, that increase the final demand. These Keynesian effects are bigger for R&D, as this input is more intensive in employment. Conversely, they are the smallest for ICT investments, as a large part of ICT capital goods are imported from outside Europe.

After 2015 up to 2019, the initial gains in GDP begin to reduce as the financing of investments

increases prices and decreases the external competitiveness of EU countries *vis-à-vis* the Rest of the World. In the case of ICT, the level of GDP is lower than that in the reference scenario between 2017 and 2021, even if it begins to re-increase after 2018.

Figure 5.5.1 – Scenarios T1605, T2605, T3605: Change in GDP in % compared to the reference scenario



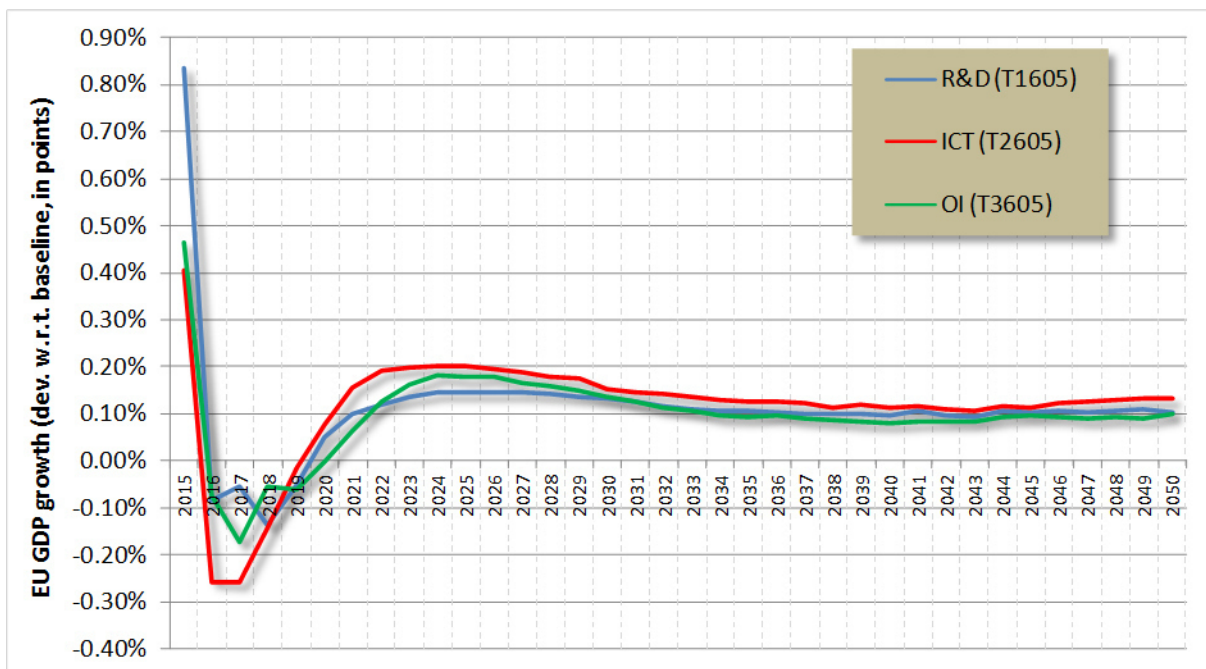
Source: NEMESIS model

The second period, that begins after 2019-2020 and that goes about up to 2035, is the “*innovation*” phase. During this period, the knowledge externalities provoked by the investments grow fast and the arrival rate of new innovations gradually reaches its maximum. The main effects on GDP come from the new process and product innovations that raise the competitiveness of EU producers.

The third period, that begins approximately in 2035, is the “*transition*” period when the growth rate of GDP stabilizes on its new long term growth path.

A second and complementary way to look at the impacts on GDP is to compare, instead of its level, the growth rate of GDP to its growth rate in the reference scenario of the model, as displayed on figure 5.5.2.

Figure 5.5.2 – Deviation in points of GDP growth compared to the reference scenario (T1605, T2605, T3605)



Source: NEMESIS model

The curves on this figure confirm the evolution in the three phases we just described. We see notably that after 2035, the annual growth rate of GDP increased by about 0.1% per year in the case of R&D, 0.12% for ICT and 0.09% for OI investments.

In the long term, we can therefore conclude, from this first set of simulations, that ICT investments are the innovation inputs that have the greater impact on the growth of EU GDP in the long term, but this first statement must be nuanced.

First, the various assets have “pulling” effects on one another and the literature indicates that these effects could be particularly strong for ICT investments. The figure 5.5.2 displays the “pulling” effects that were measured by the model for each of the simulations.

Table 5.5.2 – “Pulling” effects calculated by the model (T1605, T2605, T3605)

Scenario name	Investments in GDP points			
	RD	ICT	OI	Total
T1605 - RD	0.50	0.10	0.18	0.78
T2605 - ICT	0.17	0.50	0.26	0.93
T3605 - OI	0.12	0.10	0.50	0.72

Source: NEMESIS model

For R&D, we see that increasing the investments of 0.5 GDP point exogenously leads in the long term (after 2035) to 0.1 GDP point additional investment in ICT and to 0.18 GDP point additional investment in OI. The total rise of investment in innovation inputs is not 0.5 but 0.78 GDP point, each € invested in R&D leading in the long term to 0.56 additional € investment in the two other innovation inputs.

For OI, the pulling effect on ICT investments is identical to that of R&D but the pulling effect on R&D is inferior to the one of R&D on OI investments. Each € invested in OI leads in average to 0.44 € additional investment in the two other assets.

For ICT, as suggested by the literature, the pulling effect is very important for both OI and R&D investments. Each € invested increases OI by 0.52 € and R&D by 0.34 € and total investments in the two assets by 0.86 €.

The relative amplitude of the GDP impacts of the different inputs are therefore strongly influenced by these pulling effects, that have different amplitudes.

The next question is: Are these measured impacts on GDP in line with the findings of the literature on R&D and innovation?

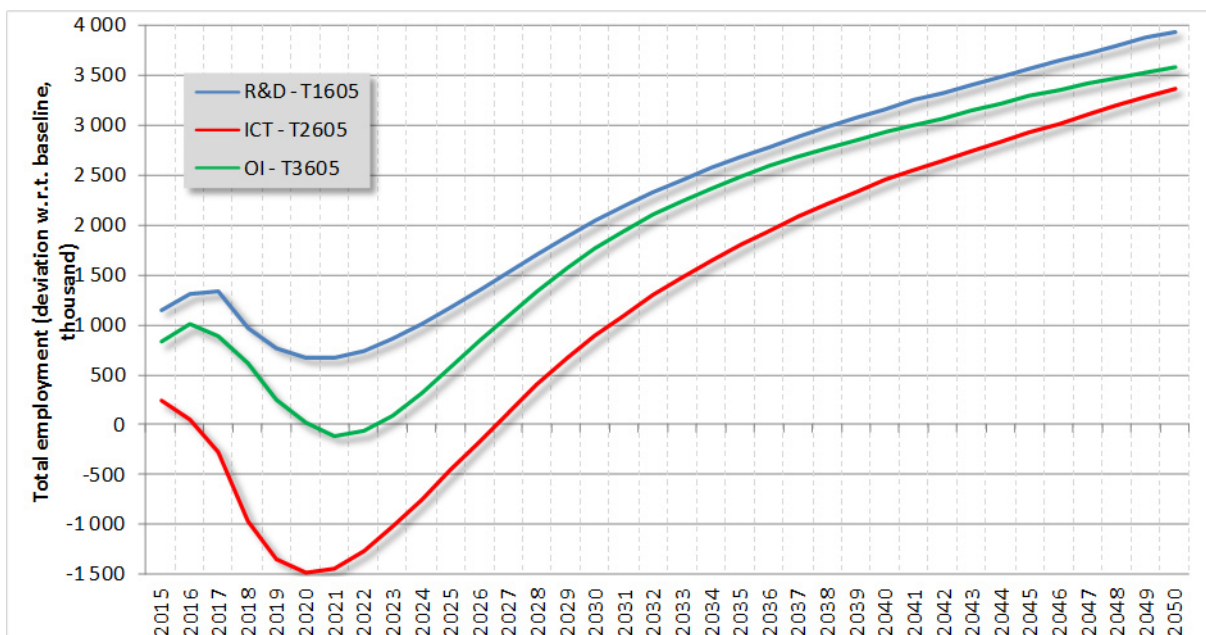
For R&D, we see that raising the intensity by 0.5 GDP point at EU level, leads to a 0.1% increase of the GDP growth rate, which is well within the interval given by the empirical literature. For the other innovation inputs, the results appears also in phase with the output and TFP elasticities calculated by the literature, but we will need additional confirmations as underlined in section 3.3²³.

To focus on employment, on figure 5.5.3 the impacts are very contrasted depending on the input

²³More precisely, in the reference scenario of NEMESIS, the intensities of innovation inputs are kept constant, close to their 2012 values. The global intensity is about 5.4% of GDP EU average, with 1.3% for private R &D, 0.7% for Public R &D, 1.1% for ICT and 2.2% for OI. It induces an endogenous growth rate of GDP/capital in the model of about 0.5-0.6% per year in EU average. The endogenous growth rate of TFP is about 0.3-0.4% per year

targeted by the shock.

Figure 5.5.3 – Impacts on total employment (deviation w.r.t. baseline, in thousand; T1605, T2605 and T3605)

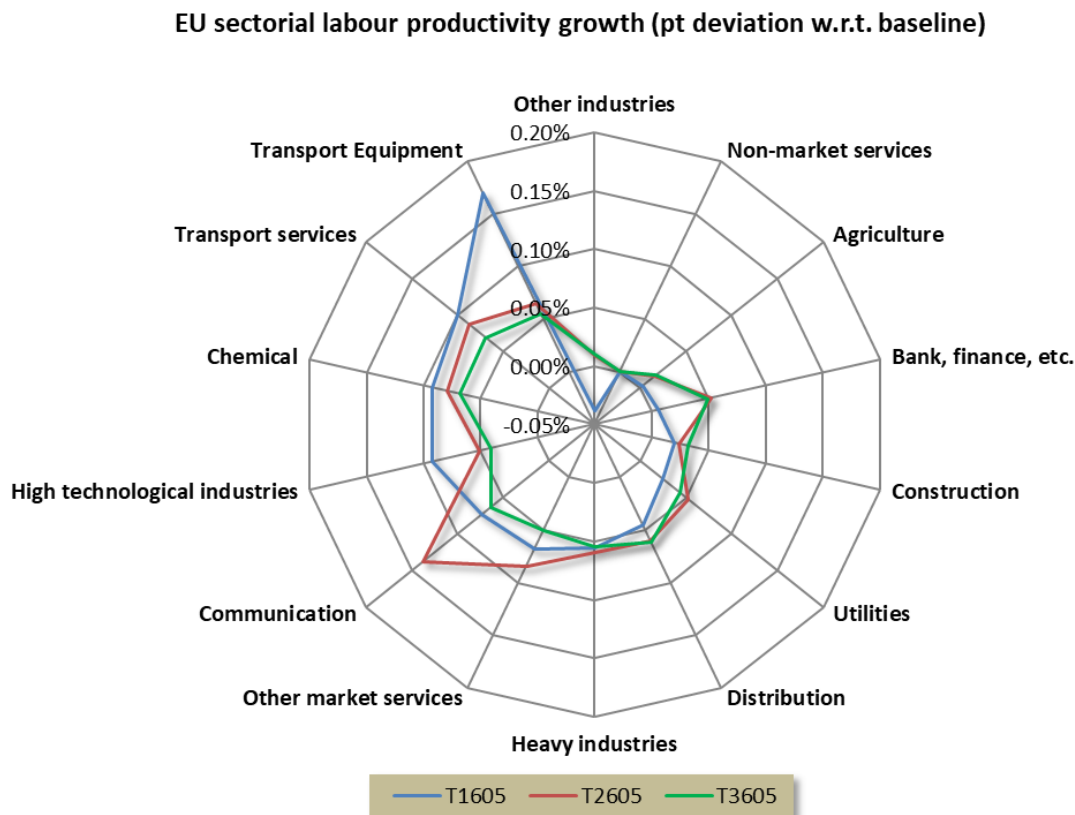


Source: NEMESIS model

While the impact on employment is always positive for R&D, with already more than 1.1 million job creations the year of the shock (2015), the impacts for ICT are very limited in 2015 (0.2 million) and then become negative, with a peak of about 1.5 millions jobs destroyed in 2020. On this date, job creations are about 0.7 million in the case of R&D and there is limited job destruction (inferior to 0.1 million) in the case of OI investments. After 2020, the level of employment re-increases in every scenario, but the difference in the relative impacts remains very large up to 2050. There is a difference of about 0.6 million jobs in the best performing case (R&D) compared to the less well performing one (ICT).

One major reason for these different impacts is that the distribution of the three inputs in production sectors are themselves very contrasted. R&D is concentrated in manufacturing and exporting sectors, ICT investment in labor intensive service industries, while OI are more homogeneously spread over the different production sectors. For example (Figure 5.5.4), R&D investments greatly boost annual long term labor productivity growth in intensive industrial sectors such as Transport Equipments, Chemicals (including pharmaceutical) and High Tech industries, notably the ICT sectors.

Figure 5.5.4 – Impacts on the long term annual growth rate of labor productivity in EU-28 sectors (deviation w.r.t. baseline in difference; T1605, T2605 and T3605)



Source: NEMESIS model

By contrast, the impacts of ICT investments on labor productivity are less important for ICT than for R&D in most industrial sectors, but they are more important in many service industries such as Communications, Distribution, Energy Utilities and in Other Market Services. Therefore, concentrating productivity gains in service sectors, that are very intensive in employment and operate principally on the domestic market, may lead to losses in employment in these sectors in the short to medium term, according to the simulations and the mechanisms of the NEMESIS model²⁴.

²⁴The distinct impacts of the innovation inputs of labor productivity will be even more contrasted if we remove the “pulling” effects between them, as seen in the next section.

5.5.3 The role of complementarities and the pulling effects

We now look at the implications of changing the value of the substitution elasticity between the three innovation inputs. Different simulations were run, with values ranging from close to zero (0.01) – perfect complementarity – to close to one (0.99) – perfect substitutability (Table 5.5.3).

Table 5.5.3 – Substitution elasticity between innovation components and “pulling” effects

			Private R&D	ICT	OI	Total
R&D	T1705	0.01	0.50	0.11	0.20	0.80
	T1605	0.25	0.50	0.10	0.18	0.78
	T1805	0.5	0.50	0.09	0.16	0.75
	T1905	0.75	0.50	0.06	0.12	0.69
	T11005	0.99	0.50	0.05	0.08	0.63
ICT	T2705	0.01	0.19	0.50	0.29	0.98
	T2605	0.25	0.17	0.50	0.26	0.93
	T2805	0.5	0.15	0.50	0.22	0.87
	T2905	0.75	0.13	0.50	0.17	0.80
	T21005	0.99	0.11	0.50	0.10	0.71
OI	T3705	0.01	0.14	0.11	0.50	0.75
	T3605	0.25	0.12	0.10	0.50	0.72
	T3805	0.5	0.10	0.08	0.50	0.69
	T3905	0.75	0.08	0.07	0.50	0.65
	T31005	0.99	0.06	0.04	0.50	0.60

Source: NEMESIS model

The first effect of changing the elasticity is to modify the pulling effect that one asset has on the investment in the two others. For R&D, the pulling effect on the two other assets is 0.28 GDP point, for a substitution elasticity of 0.25 as stated above. It is nearly unchanged (0.3 GDP point) when the substitution elasticity is lowered to 0.01. If, on the contrary, we increase it from 0.25 to 0.5, the pulling effect is also only marginally changed (0.25 GDP point against 0.28 in the default case). The pulling effect decreases to 0.19 for an elasticity of 0.75 and to 0.13 for an elasticity of 0.99. Between the two extreme cases – perfect complementarity (T1705) and perfect substitutability (T11005) – the pulling effect is reduced by about 45% ($1-0.13/0.3$). In the more acceptable or plausible range of values for this elasticity, say between 0.25 and 0.75, the amplitude of reduction of the pulling effect is limited to about 30% ($1-0.19/0.28$). For ICT and OI, the statements are similar. The importance of the pulling effect does not seem to change as much in the range of the acceptable values for the substitution elasticity.

Table 5.5.4 – Substitution elasticity, pulling effects and GDP impacts

		Elasticity of substitution	GDP*	Long-run GDP growth (2030-2050)**
R&D	T1705	0.01	3.9%	0.11%
	T1605	0.25	4.1%	0.11%
	T1805	0.5	4.3%	0.11%
	T1905	0.75	4.3%	0.11%
	T11005	0.99	4.3%	0.11%
ICT	T2705	0.01	4.4%	0.13%
	T2605	0.25	4.2%	0.13%
	T2805	0.5	4.1%	0.12%
	T2905	0.75	3.9%	0.11%
	T21005	0.99	3.6%	0.10%
OI	T3705	0.01	3.6%	0.10%
	T3605	0.25	3.5%	0.10%
	T3805	0.5	3.3%	0.09%
	T3905	0.75	3.0%	0.08%
	T31005	0.99	2.7%	0.08%
* : % deviation w.r.t. baseline, in 2050				
** : average annual growth, deviation w.r.t. baseline, in % points				

Source: NEMESIS model

As a consequence, when looking at the results on table 5.5.4, we observe that the long term GDP impacts only change slightly with the value the elasticity, at least in the interval [0.25; 0.75]. The value of this elasticity is therefore not “critical”. This is true for EU GDP, but we can check that it is also true for the main other socioeconomic indicators calculated by the model.

The reason for this result, that appears counter-intuitive, is that the main vector of complementarities between innovation inputs are the knowledge externalities. In our experiments, a rise in knowledge externalities decreases the cost of the input targeted by the 0.5 GDP shock (R&D for example), that also translates into the cost of the corresponding innovation component.

The more innovation inputs are complementary (low value of the substitution elasticity), the less the fall in the relative cost of the targeted input decreases the investment in the two other inputs, through the direct “substitution” effect. The influence of that “direct” substitution effect is measured by the changes in the different figures in table 5.5.3, when moving the value of the substitution elasticity.

But the fall in the cost of the input targeted by the shock, coming after the rise of knowledge externalities related to this asset, also transfers into the cost of innovations that decreases. Firms consequently decide to invest more in innovations, which provokes a rise in the investment in the two inputs not targeted by the shock. This is the “*expansion*” effect. It acts in the opposite direction to the direct substitution effect and proves, according to the simulation results, to be the strongest of the two effects.

But other complementarities exist in the model between the three innovation inputs. For example, the strategic complementarities between ICT users and ICT producers, may also explain why the ICT are the inputs with the strongest pulling effects on the two others.

5.5.4 Removing the pulling effects

Here we analyze in more detail the distinct impacts that the three innovation inputs decide on the growth rate of GDP.

The idea is to remove the pulling effects that one asset has on the two others in the simulation experiments. For that, the equations E1-E3 (in table 5.3.2) for the demand for innovation inputs have been removed and, in the simulations, all the innovation inputs are consequently exogenous. The shocked input is increased exogenously to 0.5 GDP point and the levels of the two other inputs are kept constant, to their values in the reference scenario of the model.

The first scenario for R&D (table 5.5.5), T1105, is similar to the scenario T1605 presented in the section 5.5.3 above, with the difference that this time there are no pulling effects of the increased investments in R&D on the investments in ICT and in OI. This scenario, though not realistic again, consequently allows for the perfect isolation of the specific impacts that the investments in R&D have on EU GDP.

Table 5.5.5 – GDP impacts without pulling effects and role of knowledge externalities

		Inter- sectoral spillovers	Intra- sectoral spillovers	GDP *	GDP growth **
Private R&D	T1105	Yes	Yes	2.6%	0.04%
	T1205	No	Yes	2.3%	0.04%
	T1305	Yes	No	2.2%	0.05%
	T1405	No	No	1.8%	0.05%
ICT	T2105	Yes	Yes	1.9%	0.04%
	T2205	No	Yes	1.5%	0.04%
	T2305	Yes	No	1.0%	0.04%
	T2405	No	No	0.4%	0.04%
OI	T3105	Yes	Yes	2.5%	0.06%
	T3205	No	Yes	1.5%	0.05%
	T3305	Yes	No	1.6%	0.06%
	T3405	No	No	0.7%	0.06%
*: % deviation w.r.t. baseline in 2050					
**: point deviation w.r.t. baseline in 2050					

Source: NEMESIS model

We first observe that removing the pulling effects greatly reduces the impacts on GDP. In 2050, the gains in GDP reach 2.6% against 4.1% when the pulling effects on the two other inputs are active (scenario T1605, figures 5.5.1). In the scenario T1605, about one third $(1-2.6/4.1)$ of the EU GDP gains were therefore not attributable to the rise in R&D investment, but to the rise in investment in the two other assets provoked by the pulling effects. The difference between the two simulation cases is greater for the impact on the long term growth rate of GDP. It is increased by 0.04% in the current scenario, against 0.1% in the previous one. The reduction of the impact this time is about 60% $(1-0.04/0.1)$.

Scenario T2105 is similar to scenario T1105, but, this time, for the case of ICT. We see that for ICT, removing the pulling effects reduces the impacts on EU GDP more than in the case of R&D. The GDP gain reach in 2050 1.9% in level, against 4.2% in T2605 (fall of more than 50%), and the impact on the long term GDP growth is 0.04%, against 0.12% in T2605 (fall of two thirds). The scenario T3105, that finally does the same in the case of OI, shows that OI are the input on which the impacts on EU GDP are the least influenced by the pulling effects. Their suppression only reduces the impacts

on the level of GDP (2.5% against 3.5%) by 25% and, by 33% the impacts of the long term GDP growth rate (0.06% against 0.09%).

5.5.5 Removing knowledge externalities reduces GDP level but not the long-run output growth

The other simulation results displayed in table 5.5.5 aim at analyzing the role played by the knowledge externalities, associated with the different inputs, on the impacts measured for GDP. For R&D, the simulation T1205, in addition to pulling effects, as in the case T1105, also removes the effect of inter-sectorial externalities relative to R&D, by suppressing part of equations E15 (table 5.5.5). These intra-sectorial externalities comes from both national and foreign sources (limited to other EU countries here). Similarly, the simulation T1305 removes the impacts of intra-sectorial externalities (between firms in the same sector in the same country and in the other countries) and the simulation T1405 those of all externalities.

The first observation is that knowledge externalities do not impact the long-run growth rate of output in our experiments. On the contrary, they greatly impact on its level. For instance, for R&D, the impact on the long term growth rate of GDP remains almost unchanged when all externalities are removed, but the impacts on the level of GDP are reduced in 2050 from 2.6% (T1105) to 1.8% (T1405) with a fall of about one third²⁵. For ICT, the impacts on the level of GDP in 2050 are reduced by about 80% when removing all externalities (T2405 against T2105), while, for OI, they are reduced by about 70% (T3405 against T3105).

The fact that removing knowledge externalities does not impact the long-run growth of EU GDP is intriguing, but one must keep in mind that conversely, in NEMESIS, there is no endogenous growth without growth in knowledge externalities. If the knowledge externalities remain static in the reference scenario of the model, there will be no impacts in the long term GDP growth rate when raising the intensity of innovation inputs, as illustrated by equation 5.5.4.

5.5.6 The importance of product innovations

The last experiments, presented in table 5.5.6 (for GDP) and table 5.5.7 (for employment), illustrate the role played by product innovations. First we remove product innovations and only keep process

²⁵For R &D, the role played by knowledge externalities is in reality greater if we account also for externalities from public research.

innovations (scenario T11205); then we retain the same number of process innovations and progressively increase the number (share) of product innovations (scenarios T11035 to T11505). We only present the results obtained for the case of R &D, as the results for ICT and OI are similar.

In our default calibration setting, summarized in table 5.5.1, we fixed the share of product innovations at 0.33%: process innovations are twice as important (in number) than product innovations. This corresponds in table 5.5.6 and table 5.5.7 to the case T1105, we studied in section 5.5.4.

As for scenario T1105, in all the simulations presented here, the pulling effects were removed and equations E1-E3 (table 5.5.5) for the demand of innovation inputs were suppressed. The R&D was increased exogenously to 0.5 GDP point, and the level of the two other inputs were kept constant to their values in the reference scenario of the model.

In scenario T11405 (see table 5.5.6), product innovations were removed while the “quantity” of process innovations was identical that in our central scenario T1105: it was normalized to 1. Starting with the results for GDP, we see that removing product innovation reduces the impacts on GDP considerably, whatever the time horizon considered. In 2050, the increase in EU GDP is reduced 2.6 points (about two thirds) compared to the situation in our central scenario, T1105, where this share is set at 33%. During the “investment” period (2015-2020), the negative impacts on the GDP annual growth rate are nearly doubled : they reach -0.09 point against only -0.05 in T1105. Similarly, in the “maturation” (2020-2035) and the “transition” (2035-2050) periods, the positive impacts on GDP are reduced by about 50%.

Table 5.5.6 – The impact of product innovations (GDP)

	Quantity of innovations				GDP [*]	GDP growth ^{**}		
	Process innovations (1)	Product innovations (2)	Total innovations (1) + (2)	Share of product innovations (2)/(1+2)		2015-2020	2020-2035	2035-2050
T11405	1	0.00	1.00	0%	1.2%	-0.09%	0.04%	0.02%
T1105	1	0.50	1.50	33%	2.6%	-0.05%	0.09%	0.04%
T11505	1	1.00	2.00	50%	4.0%	-0.01%	0.15%	0.07%

^{*}: % deviation w.r.t. baseline, in 2050

^{**}: change in annual average growth rate compared to ref. scenario in % points

Source: NEMESIS model

The reason for these higher negative GDP impacts in the short term, and reduced positive ones in the medium to long term, is that when removing product innovations, process innovations reduce production costs and will gradually compensate by financing extra R&D expenditures, but they have

also a direct negative impact on employment and on the demand for the other production inputs that lead to recessive effects. As we saw, the results would be similar if we increase the elasticities α_{cit} , that measure the “strength” of process innovations at sectorial level. The only way to avoid these negative impacts would be to increase the price elasticity of demand ε_{cit}^D , to allow a higher response to the price decrease provoked by process innovation, but this would not be consistent with the consumption behavior of the different economic agents in the model.

Table 5.5.7 – The impact of product innovations (Employment)

	Quantity of innovations				Employment [*]	Employment growth ^{**}		
	Process innovations (1)	Product innovations (2)	Total innovations (1) + (2)	Share of products innovations (2)/(1+2)		2015-2020	2020-2035	2035-2050
T11405	1	0.00	1.00	0%	0.3%	-0.07%	0.01%	0.00%
T1105	1	0.50	1.50	33%	1.2%	-0.04%	0.05%	0.01%
T11505	1	1.00	2.00	50%	2.1%	0.00%	0.08%	0.02%
* : % deviation w.r.t. baseline, in 2050								
** : change in annual average growth rate compared to ref. scenario in % points								

Source: NEMESIS model

When, on the other hand, the quantity of process innovation is increased to reach 50% of all innovations - still keeping the amount of process innovations constant at 1 - (scenario T11405), the impact on the level of GDP is increased by 2.4 point in 2050 (about 50%), compared to T1105, and the rise in the long term GDP annual growth rate during the “maturation” (2020-2035) and the “transition” (2035-2050) periods also increased by about 50%. Therefore we see that the GDP impacts increase almost proportionally to the number of product innovations that are introduced in the model.

These last results confirm the very important role played by this “sharing“ between product and process innovation, that is controlled in the model by the value of the parameters m_{ci} . For employment (table 5.5.7), the conclusions are similar: the impacts increase almost proportionally to the number of product innovations introduced in the model.

5.5.7 On convergence in GDP/capita

A last important point to examine is the type of convergence in GDP/capita implied by our modeling. Surveying the development of literature on endogenous growth, Howitt (2004 [260]) notably underlines that when introducing international technology transfers from trade or international knowledge exter-

nalities, as in our approach, the theory suggests that this convergence should occur, “(...) *making it consistent with the observation of convergence in growth rates over the past half-century*”.

Moreover the literature shows that the countries that do not invest much in technology and in R&D “(...) *are not able to benefit from technology transfer, (and) will not converge in growth rates but will instead grow more slowly than the technology leaders, even in the long run*”. Investment in education and the level of educational attainment of the workforce are other important channels of technology transfers in both empirical (e. g. Griffith *et al.*, 2001 [136]) and theoretical (e. g. Howitt *et al.*, 2002 [166]) studies.

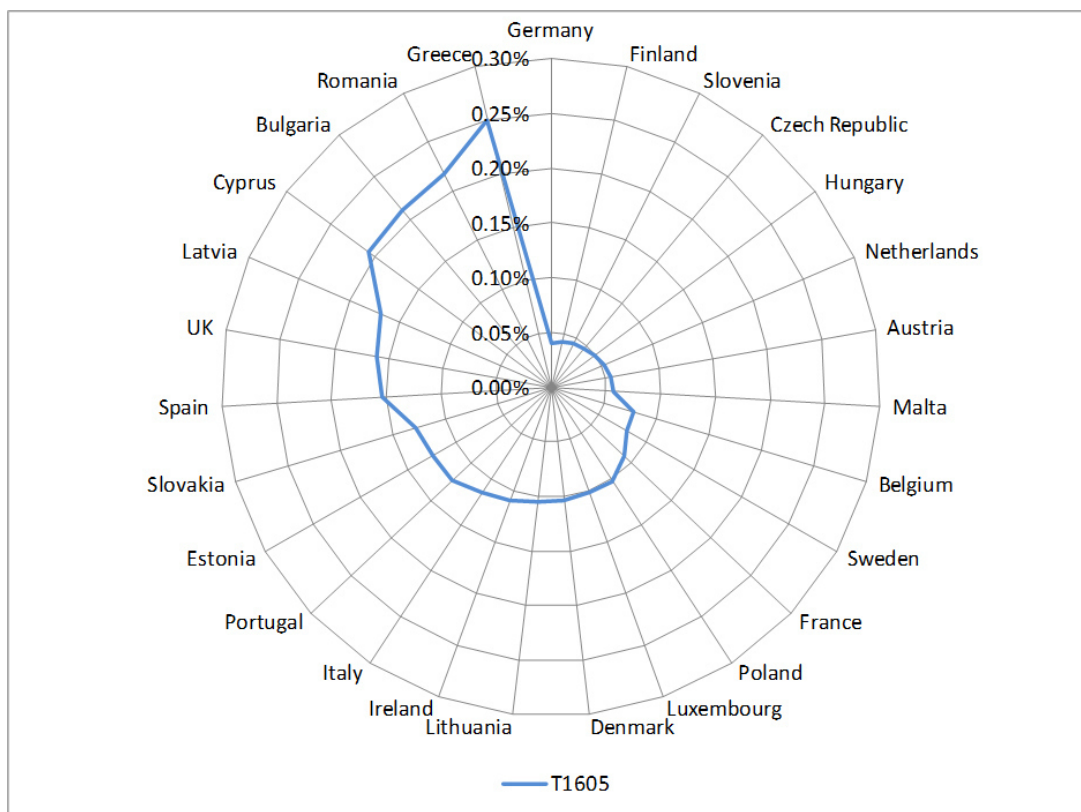
All these results suggest that per capita income of the countries will not converge systematically, but only for countries with strong interactions and sharing similar characteristics. This is the club-convergence hypothesis illustrated notably by Quah (1996 [307]).

In European countries, one observes an East-West and a North-South European divide described by R. Veugelers (2014 [273]) in the case of R&D. Most eastern and southern countries have a R&D effort well below the EU average, while most of the countries belonging to the central and northern European groups are above this EU average. This European divide also exists for investments in education and in OI but not for investments in ICT.

When simultaneously increasing the R&D intensity in all EU countries by 0.5 GDP point, as in the scenario T1605, the NEMESIS simulation results show (figure 5.5.5) that the countries from the east of Europe, which are also on average the less R&D intensive, encounter greater impacts in terms of GDP growth. This shows a catch-up effect in these countries creating a very important R&D effort compared to their initial historic situation in the scenario. Their ability to absorb knowledge externalities (pre-existing or occurring in the T1605 scenario) is notably considerably increased compared to the situation in the reference scenario. This catch-up phenomenon is also observable for the countries from south Europe, well above the EU average in terms of R&D intensity. The question finally is the reality of these changes and the possibility these countries have to introduce structural reforms that will incite firms to increase their R&D efforts to such a level.

5.5.5

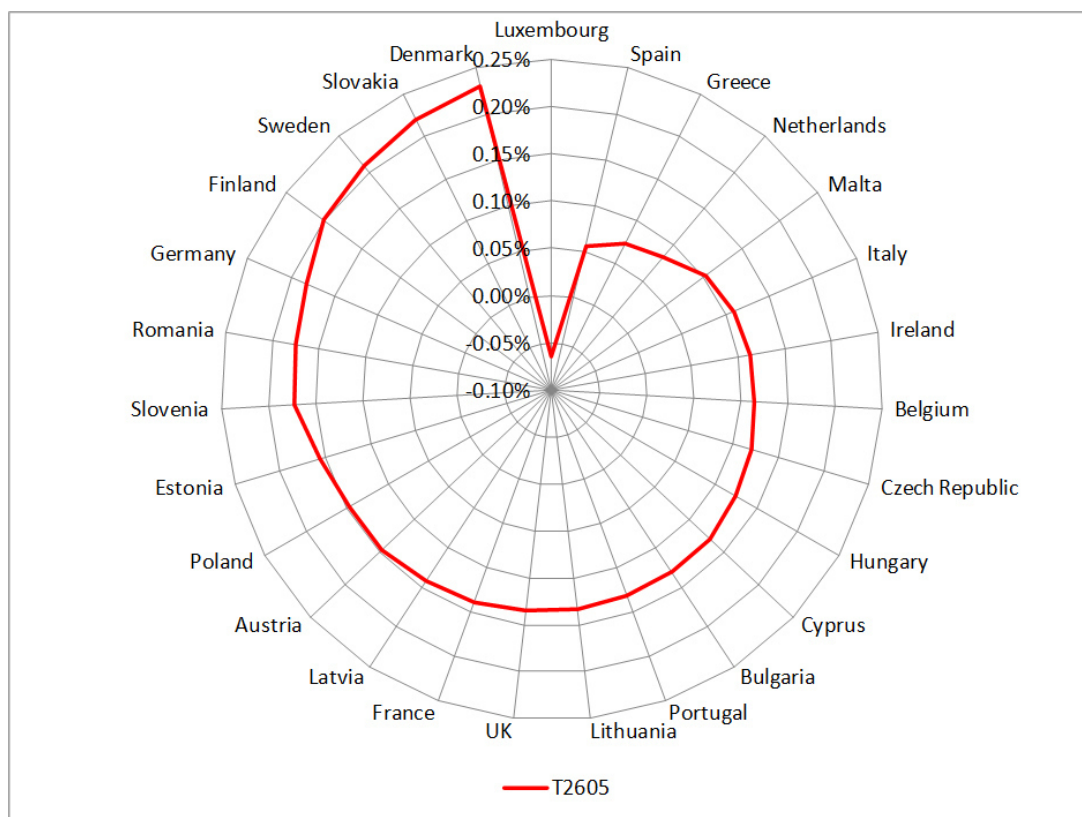
Figure 5.5.5 – Impact on long term annual growth rate of GDP per capita (T1605 - R&D)



Source: NEMESIS model

In the case of a rise of investment in ICT (scenario T2605, figure 5.5.6), the countries from the north of Europe, that are also among the more intensive in R&D, encounter the greatest impact on their long term GDP growth. These countries benefit notably greatly, compared to eastern and southern countries, from the strong pulling effects that ICT investments have on R&D.

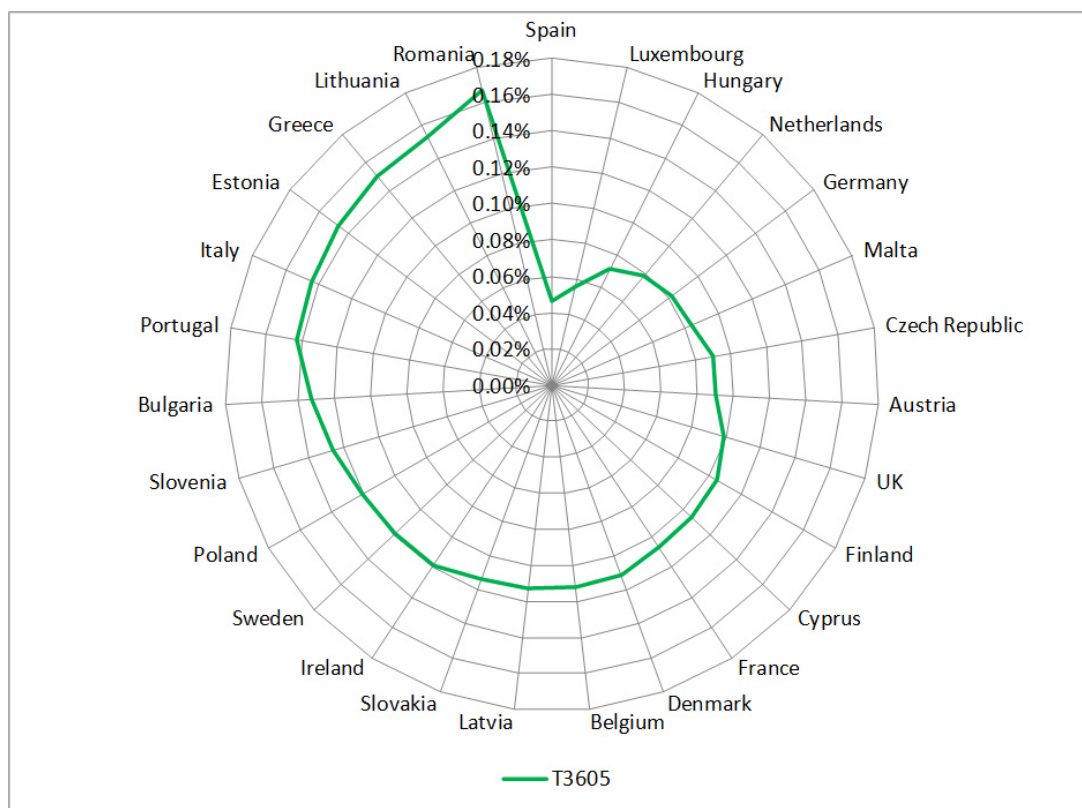
Figure 5.5.6 – Impact on long term annual growth rate of GDP per capita (T2605 - ICT)



Source: NEMESIS model

In the last case of a rise in OI investments (T3605, figure 5.5.7) the simulation results once again display the catch-up phenomenon in eastern and southern countries obtained for R&D. The reasons are similar: these countries make, in the scenario, a very important investment effort compared to their initial historic situation, allowing them to better absorb international knowledge externalities.

Figure 5.5.7 – Impact on long term annual growth rate of GDP per capita (T2605 - OI)



Source: NEMESIS model

These last results therefore confirm that the innovation mechanisms introduced in NEMESIS are in phase with the club-convergence hypothesis illustrated by the recent literature on endogenous growth.

5.6 NEMESIS: A useful bridge between Micro and Macro

This chapter presented the new innovation module of NEMESIS that was developed in the context of the EC research project SIMPATIC. Compared to the previous version based on the R&D input alone (see chapter 4), this new version, notably better represents the new forms taken by innovation in recent years. These mainly concern organizational innovations, where development is accelerating with the fast expansion of the broadband infrastructure and ICT investments. The bulk of innovation is not longer related to R&D investment by high-tech sectors, but to new marketing or organizational methods, new workplace organizations, new linkages between producers or between producers and customers, etc, helped by ICT investments and investments in OI assets (Software and Training in our modeling).

This new representation of innovation at the same time allows a better description of the way firms innovate in the information age, and of the interactions among the different production sectors of the economy, notably between manufacturing and services. These latter sectors, that were considered as not progressive became progressive because of adaptations of ICT technologies (Jorgenson et al., 2008 [185], Colecchia and Shreyer, 2001 [67], 2002 [68], Bosworth and Triplett, 2007 [37], van Ark, O'Mahony and Timmer, 2008 [316]) and their investment in complementary intangible assets, notably human capital (Corrado *et al.*, 2012 [74]).

Our modeling approach, based on the endogenous growth theories à la Romer (1990, [284]) and on the concept of ICT as GPT proposed first by Bresnahan and Trajtenberg (1995 [43]), is to our knowledge the first attempt to extend the range of innovation inputs in a large scale macro-sectorial simulation model used for the assessment of R&I policies. The main assumption underlying our modeling is that there exists, as for R&D, specific knowledge externalities associated with the investments realized in ICT and OI that we model explicitly.

While our first simulation experiments show that the model results are in phase with the key findings in the recent literature on innovation, they nevertheless remain preliminary as the required data from national accounting sources is very scarce as well as the literature on ICT and OI.

This new version of NEMESIS finally enriches the range of R&I policies that can be assessed with the model considerably. This version was used in I3U to achieve an assessment of the European Innovation Union, that we present in the chapter 7. For I3U the “*by-default*” calibration of the model used in this chapter was adapted to represent the specificities of the R&I policy interventions that were studied. It was based on in-depth direct assessments of the 34 commitments of the Innovation Union using micro works, that were the inputs that then allowed NEMESIS to calculate their socioeconomic and environmental indirect impacts.

The micro works notably allowed us to re-calibrate three sets of “*parameters*” that proved very important for the assessment of R&I policies: (1) the additionality or leverage effect of the different European R&I policies on investment in innovation inputs, (2) the specific knowledge externalities they provoke and (3) the way they modify the productivity of knowledge.

Micro and Macro therefore prove to be very complementary approaches for the assessment of R&I policies, notably using the Meso detailed sectorial modeling of NEMESIS that usefully bridges these former, as illustrated in this chapter.

Part III

The Evaluation of EU R&I Policies with NEMESIS

Chapter 6

Horizon 2020 - Interim Evaluation

Between October 2015 and February 2017, the NEMESIS model was used for the *ex-post* evaluation of the European Commission (EC) 7th Framework Programme (FP7) for R&I, that covered the period 2007-2013, and for the interim evaluation of its successor, the Horizon 2020 (H2020) programme, that began in 2014 and will end in 2020.

These evaluations were conducted in the context of a support study to the Directorate A5 “*Better Regulation*” of the DG Research, in charge of the evaluation of the European research policy. This study was coordinated by the Public Policy and Management Institute (PPMI) in Vilnius in Lithuania, that we supported with NEMESIS for the evaluation of the Socioeconomic and Environmental Impacts (SEEI, thereafter) of the programmes (PPMI, 2017, [272], and European Commission, 2017, [71]).

The aim of these evaluations was twofold:

1. Assessing the European Added Value (EAV) of FP7 and Horizon 2020 programmes, that is the value resulting from the action conducted at the EU level, in addition to the value that would be created if the intervention was at the level of a member state. The definition of EAV used includes both establishing the needs for public intervention, as opposed to market forces, and for public intervention at EU level, as opposed to national or regional policies. This was analyzed in the study around three main dimensions (effectiveness, efficiency and synergy), covering ten different areas, on which the EU intervention could impact:
 - (a) Addressing of societal/Pan-European challenges;
 - (b) Coordination of national research policies and practices;
 - (c) Wider availability and dissemination of knowledge;
 - (d) Pooling resources and building critical mass;
 - (e) Reduction of research risk;
 - (f) Reduction of commercial risk;
 - (g) Increased competition in research;
 - (h) Leverage of private and public investment;
 - (i) Improving research capabilities;
 - (j) Increased international and/or inter-sectorial mobility of researchers;
 - (k) Reduction of commercial risk.

2. Providing a robust assessment of the SEEI for FP7 and Horizon 2020 programmes, in order to better understand what the drivers and obstacles to innovations are, and to assess how Horizon 2020 can generate increased economic returns in the future. The evaluation carried out analysis of the economic impacts at micro/project and macro/sectorial levels.

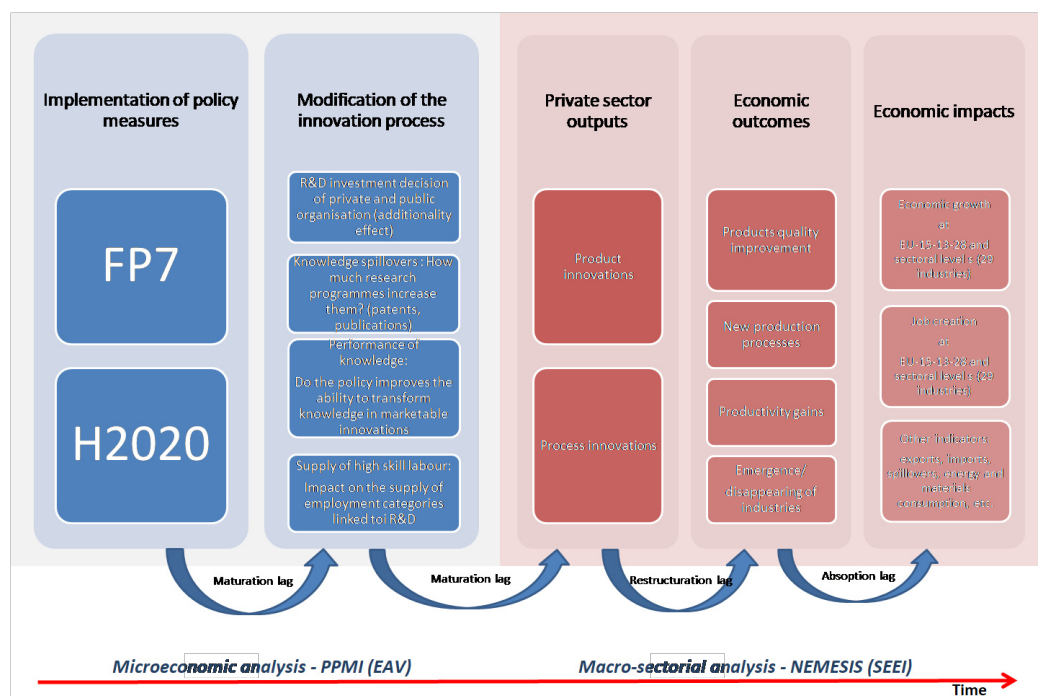
Concerning the methodology, the study included different approaches from micro to macro analysis:

1. The assessment of the EAV of FP7 and H2020 was based on micro works achieved by PPMI, including notably:
 - (a) The elaboration of a survey on FP7 beneficiaries and on FP7 unsuccessful applicants/high quality research teams, to constitute a control group for the analysis of the EAV. 1157 responses were received for FP7 beneficiaries and 462 for the control group, that allowed us to collect sufficient data for a robust assessment of EAV.
 - (b) A separate survey on H2020 beneficiaries, with about 1000 responses received, in order to learn more about the expected impacts of H2020 ongoing projects and programmes.
 - (c) A bibliometric analysis, to assess the “*scientific EAV*” of the FP7, combining a traditional bibliometric approach, with a counterfactual analysis design comparing the productivity of researchers inside and outside the FPs.
 - (d) A patent analysis involving, here again, a robust counterfactual analysis design comparing the quality of FP7 patents, with a comparable group of patents produced outside the FPs, according to 9 criteria.
2. The assessment of the SEEI¹ for FP7 and H2020 was achieved by applying the NEMESIS model. The methodology, as illustrated by figure 6.0.1, consisted of using the results of the micro analysis that was performed by PPMI using data on FP7 and H2020 programmes, for modifying key parameters (or mechanisms) of the model, that were notably informed and fine-tuned, using the estimates from counterfactual micro-level analysis on three points:
 - (a) The impact of the policies on the R&D investment decisions of private and public organizations: How much additional investment will one euro funding by the EC provoke?
 - (b) How does the EU policy modify research productivity and knowledge creation compared to national programmes?

¹Socio-Economic and Environmental Impacts.

- (c) Does the research financed by the EC have a higher economic performance in terms of economic outcomes, than national programmes?

Figure 6.0.1 – Methodology of the assessments of SEEI of FP7 and H2020 using NEMESIS



Source: Adapted from PPMI, 2017

An important point concerning the methodology is that there are important time lags between the introduction of a policy, and the time the first economic impacts will develop. There are lags between the time the policy is adopted and the time it is implemented, between the time it influences the R&D decision and the time it creates research results such as publications or patents, between the time the new scientific and technological knowledge is produced and the time it becomes product and process innovations and, finally, between the time the innovations are introduced and the time they diffuse in the economy and produce their full SEEI. The typical time-length for this chain of impacts to occur is about fifteen years in the NEMESIS model. Also, as the R&I policies modify the production of knowledge, their impacts last long after the end of the policy, until the total obsolescence of the knowledge they contributed to. And as most of the impacts appear after the end of the policy, the assessment of R&I policy is never truly *ex-post* and remains to a large extent *ex-ante*.

In this chapter, we limit the presentation to the interim assessment of the H2020 programme, but

the reader interested in FP7 results could refer to European Commission (2017, [71]).

As the H2020 programme only began in 2014, the interim evaluation of H2020 presented here, that was achieved in 2017, has obvious limitations. The impacts of the policy on indicators such as the number of new patents and publications, new prototypes or industrial designs, new processes and products, competitiveness and sales of innovative products, ... were just starting at the time of the evaluation, because of the diffusion lags. For this reason, a large part of the evaluation was based on the results obtained for the FP7 programme concerning the assumptions that were retained for the EAV of H2020. These assumptions are crucial as they are used (see figure6.0.1) to re-calibrate the NEMESIS model to take into account the specificities of the European R&I policy, compared to the national ones, on which the model was originally calibrated.

The next section begins by presenting the outline of the H2020 programme, with its three pillars, plus the precise scope of the evaluation made with NEMESIS. Then, after a detailed presentation of the methodology used to implement the H2020 programme in the model, the following sections summarize the main results of H2020 SEEI at macro and sectorial levels. The last sections also present simulation results involving sensitivity analysis on the main assumptions retained for the model parameters, and the results of a scenario that we have called “*H2020 forever*”, where, by assumption, the H2020 programme will continue forever after 2020. This last scenario notably allows us to illustrate the long term impacts of the EC FP, and to compare the results of this *interim* evaluation with the ones of the previous *ex-ante* evaluation that was achieved in 2011 (European Commission, 2012, [115]), and was based on a “*H2020 forever*” methodology.

6.1 The H2020 programme

The Framework Programmes are the EU’s main instruments for the funding of R&I in Europe. Horizon 2020 is the eighth EU’s FP for R&I, with a budget of about 80 billion current euros.

Looking at the evolutions using FP7 to H2020 programmes, the changes concern notably:

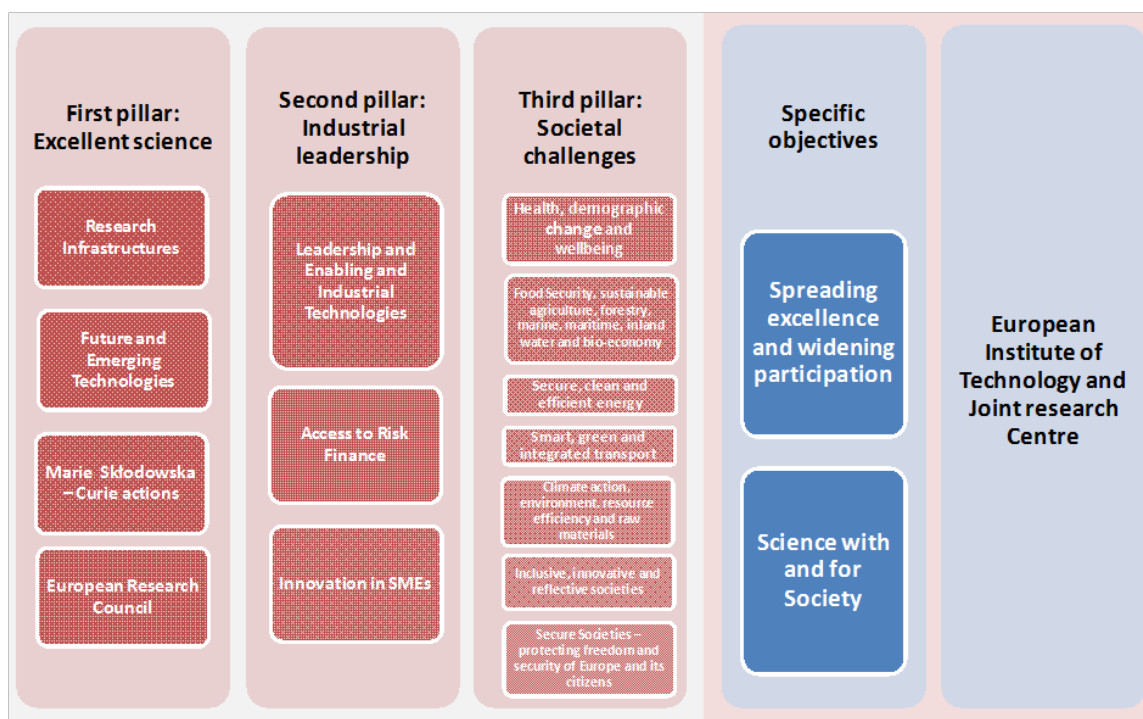
1. The total budget allocated that grew from 50 billion for FP7 to 80 billion for H2020 and compared to FP7, H2020 could fund up to 100% of costs² (excluding the “*close to market*” actions where

²For comparison, the standard reimbursement rate for research and technological development activities was 50% for FP7. Non-profit public bodies, SMEs, research organizations and higher education establishments could receive up to 75%. For demonstration activities, the reimbursement rate could reach 50%, and the 100% rate was applying for frontier research actions under the European Research Council.

a 70 % maximum applies, excluding non-profits) and the funding model for indirect cost was unified and is currently 25% across all pillars of the programme.

2. The overall structure of the budget. H2020 includes many themes that were addressed by FP7 (Cooperation, Capacities, Ideas, Euratom and People specific programmes) but it integrates several additional research initiatives (see figure 6.1.1) including the successor to the Competitiveness and Innovation Framework Programme (CIP, comprising the innovation related parts of the Entrepreneurship and Innovation Programme (EIP), the Information Communication Technologies Policy Support Programme (ICT-PSP), and the Intelligent Energy Europe Programme (IEE)) and the European Institute of Innovation and Technology (EIT). Also with H2020, rather than presenting already prescribed research topics, the EU funding is allocated to solve specific challenges and it encompasses more possible approaches to address them.

Figure 6.1.1 – Overall structure of Horizon 2020 (excluding Euratom)



Source: Adapted from PPMI, 2017

3. H2020 puts also an increased emphasis on the participation of business (both SMEs and large enterprises/industry). For promoting small and medium size enterprise (SME) participation new instruments or activities focusing on SMEs were introduced, particularly under the industrial

leadership and societal challenge pillars where around 20% of the budget is dedicated to SME. The JTIs that promote private/public partnership have also proven very successful in attracting a high level of industrial participation in their activities, including a high rate of SME's, and H2020 has introduced new initiatives.

4. Finally, new types of actions were introduced in H2020 including pre-commercial procurement, procurement of innovative solutions, inducement prizes, debt financial instruments and equity finance for R&I.

The general aim of the FP and H2020 is to contribute to building a society and economy based on knowledge and innovation across the Union by leveraging additional research, development and innovation funding and by contributing to attaining research and development targets, including the target of 3% of Gross Domestic Product (GDP) for research and development (R&D) across the Union by 2020. It shall thereby support the implementation of the Europe 2020 strategy and other Union policies, as well as the achievement and functioning of the European Research Area (ERA). Universities, research institutes, industry (including SMEs), management and technology transfer organizations and various associations are all eligible to participate in the programme.

6.2 Methodology to implement the H2020 programme in NEMESIS

In NEMESIS, two main families of factors permit the implementation of a policy scenario and its assessment in comparison with a reference scenario: the exogenous variables and the values of the key parameters. In the case of the EU research programmes, the first is linked to the general characteristics of the programmes that are studied using NEMESIS. This notably concerns the size and the allocation of the budget. The second is relative to the mechanisms and the value of the key parameters of the models and their ability to reflect the specificities of European policies when compared, for example, to national funding for R&I.

6.2.1 The budget and its allocation

The first element to define is the overall budget of the European Research Programme. Then its implementation in NEMESIS requires its:

- Temporal allocation;
- National allocation, *i.e.* between the different member states but also for the share allocated to non-EU countries;
- Sectorial allocation, how the national allocation is distributed among economic activities;
- Distribution in research categories, *i.e.* between Applied and Basic research.

Concerning the sectorial dimension, 30 different economic activities are modeled in NEMESIS, that differ insomuch as:

- The exposure to international competition in the different sectors is very heterogeneous;
- The diffusion of innovations in the economy (through trade, investment, final consumption, transactions between sectors, ...) is different depending on the sectors that introduce them, for example if they produce mainly investment, intermediate or final consumption goods;
- The complementarities of the research investments with the other innovation assets that are modeled in the NEMESIS model (ICT and Other Intangibles than R&D) are not homogeneous among sectors;
- And the diffusion of the knowledge spillovers between sectors and countries is also impacted by the sectorial allocation.

The research categories (*i.e.* the distinction between “*Applied*” and “*Basic*” research), do not play a symmetric role in the mechanisms of the models. “*Applied*” research is considered as a source of knowledge that can be mobilized by the sector to put innovations on the market (what we call the knowledge absorption capacity of the sector) whereas “*Basic*” research is also a source of knowledge for the sector, but its relation to market is less direct: it takes more time than applied research to transform into formal knowledge that could be useful for firms, what is more its transformation into marketable innovations can only occur if it is coupled with applied research. So, the economic performance of these two kinds of research is different and plays on different time horizons.

6.2.2 The key parameters

The second important set of factors for the analysis of R&I policies are those related to the precise innovations mechanism/parameters of the model. Generally, these mechanisms or parameters are either

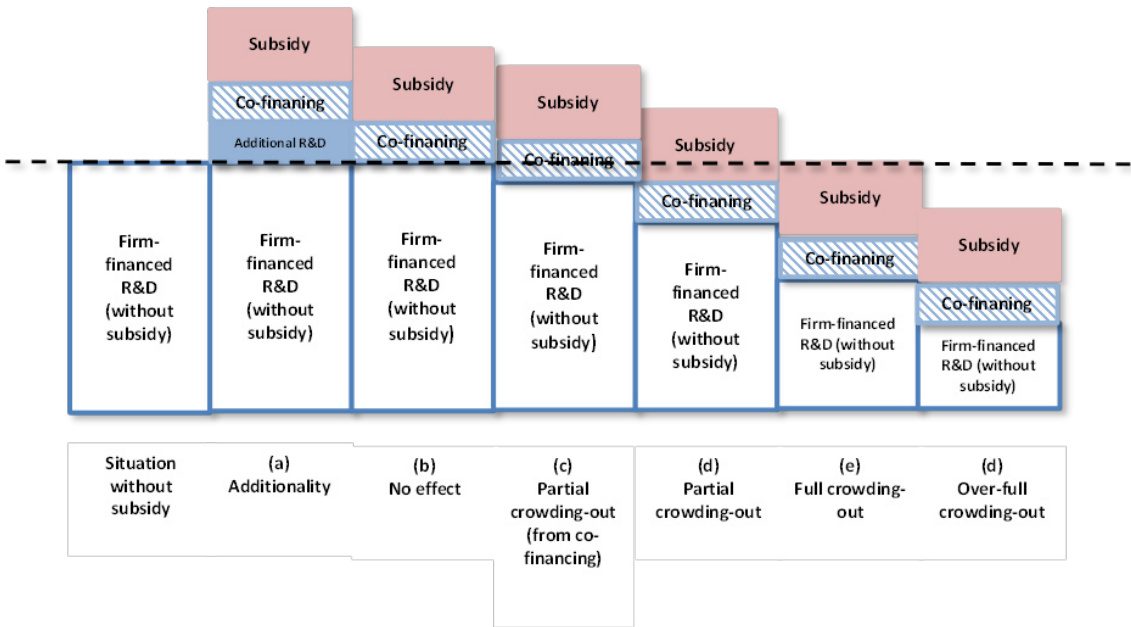
estimated by econometric methods or calibrated. The original calibration of the model is based on robust and well known estimations from the econometric literature (*e.g.* Hall *et al.*, 2009, [155]). The model uses these estimates from the literature, but as most of these works are not specific to the FP then, the the question is how these parameters are changed when this specific policy is implemented. For simplicity, we distinguish three broad categories of mechanisms/parameters that may be impacted by the FP policies:

1. The leverage effect (or crowding-in/out effect or additionality effect), *i.e.* the amount of additional research expenditures resulting from the financial support received;
2. The knowledge spillovers *i.e.* the inter-sectorial and international diffusion of the knowledge resulting from research activities;
3. The economic performance of knowledge describing the transformation of knowledge into marketable innovations and then into production increases.

6.2.2.1 The leverage effect

The leverage effect is usually defined as the variation in R&D expenditures (D) that results from 1 Euro of public funding and that leads to a total R&D expenditure of $1+D$ Euro. As a rule, the leverage effect must be the result of an optimization of the value of the representative firm at a sectorial level and then, the result of the comparison between the productivity of the marginal R&D expenditure and its cost. However, this simple mechanism does not reflect the complexity of the decision, in the sense that several important factors are not introduced in this decision making. It is the case, for example, with the risk Sharing Finance Facility (RSFF) system that reduces the risk for the R&D investor and raises the leverage effect drastically. For these reasons, the leverage effect adopted for the assessment of the FP is based on observations and empirical estimates and not on theoretical considerations.

Figure 6.2.1 – Illustrative scheme of the different cases for the leverage effect



Source: Adapted from Dimos and Pugh (2016, [100]).

However, the quantification of the leverage effect is difficult as there are potential crowding-in and/or crowding-out effects as illustrated by figure 6.2.1. To quantify the leverage effect, we use three different kinds of information (i): the total cost of projects supported by H2020 (from 2014 to 2016) and by FP7 that includes the subsidy from EU contribution and the additional funding to cover the total cost of the project; (ii) the empirical estimates of the leverage effect from scientific literature and (iii) the estimates of the leverage effect for EU research programmes coming from surveys. Nevertheless, none of these sources of information is able, by itself, to deliver a quantitative result for the leverage effect directly usable for the implementation of the EU research programmes in the NEMESIS model due to (i) overlapping between the leverage effect, the subsidy and the co-financing (see Figure 6.2.1), (ii) incomplete and partial analysis or (iii) over aggregated estimates. Therefore, we will explore all of this available information, defining its scope, its limits and finally, we will try to propose acceptable assumptions to implement the leverage effect in the NEMESIS model.

The first source of information (called co-financing), the total cost of projects supported by H2020 or FP7, appears really useful as it is direct information and complete information from projects supported by EU research Programme. Using CORDA data sources, we can quantify the co-financing for different specific programmes for FP7 and Pillars for H2020. Table 1 summarizes this co-financing effect for

Chapter 6. Horizon 2020 - Interim Evaluation

the main thematics of FP7 and H2020. For FP7, the co-financing effects measured vary significantly between thematics, from 0.0 for “*Ideas*” to 0.77 for “*Euratom*”, with on average 0.43. For H2020, the indirect costs (an important component of the total project costs) are not based on real indirect costs of participants, but they are calculated as a fixed rate (25 %) of real direct costs (lower bound). To get closer to the co-financing calculated for FP7, another methodology to estimate the “*real*” indirect costs in H2020 has been developed (upper bound): the real indirect cost/direct cost ratio of FP7 beneficiaries (private companies only) was multiplied by the direct cost declared by Horizon 2020 beneficiaries (private companies only). So in H2020, the co-financing effects range from 0.04 in “*Excellent Science*” to 0.3 in “*Industrial leadership*”, with on average 0.2 when referring to the lower bound, whereas for the upper bound the co-financing effects are respectively 0.1, 0.6 and on average 0.39.

Table 6.2.1 – The co-financing effects in the main thematic of FP7 and H2020

FP7		H2020*		
Thematic	Co-financing effect	Pillars	Co-financing lower bound**	Co-financing upper bound**
Cooperation	0.59	1. Excellent Science	0.04	0.10
Ideas	0.00	2. Industrial leadership	0.30	0.60
People	0.13	3. Societal Challenges	0.27	0.52
Capacities	0.37	Basic***	0.04	0.10
Euratom	0.77	Applied***	0.29	0.55
Total	0.43	Total	0.20	0.39

*: observed data from 2014 to 2016; **: in Horizon 2020, the indirect costs (an important component of total project costs) are not based on real indirect costs of participants, but they are calculated as a fixed rate (25 %) of real direct costs (lower bound). Another methodology to estimate the ‘real’ indirect costs in H2020 has been developed (upper bound): the real indirect cost/direct cost ratio of FP7 beneficiaries (private companies only) was multiplied by the direct cost declared by Horizon 2020 beneficiaries (private companies only); ***: Aggregation of Pillar I for Basic research and Pillar II, III plus Fast-Track to Innovation (not reported in the table) for Applied.

Source: Calculation based on CORDA data

So, as these figures displayed in table 6.0.1 reflect the support and the financial scheme implemented in the EU framework programmes, it cannot be really defined as the leverage effect. Though the

additional funding to cover the total cost of the project is a part of the leverage effect induced by EU research programmes (figure 6.2.1), it could also be complemented by:

1. Additional funds (crowding-in effect) not used directly for the project supported by EU research programmes but resulting from this support (case (a) in figure 6.2.1). For instance, it could be related to an increase in research capability, an increase in knowledge exchanges, an increase in expected market opportunities, etc., that result indirectly from the EU research support. In this case, the additional funds would not have been spent without research support from EU.
2. Co-financing required to cover the total cost of the project supported by EU funding can crowd-out other sources of funding for the research units involved in the research project supported by the EU. For instance, a firm can reduce its expected expenditures on research activities by the total amount (cases (e) and (f) in figure 6.2.1) or a partial amount (cases in (c) and (d) in figure 6.2.1) of the required co-financing to cover all project costs.

Therefore, the co-financing effect is a relatively useful information to assess the leverage effects of EU research programmes but it cannot be used directly because of potential additional crowding-in or crowding-out effects not observed in the data.

The second main source of information on the “*leverage effect*”³ of public support for research activities is the literature. Before we study the main results in the empirical literature, we must note some elements. There are two main questions concerning the implementation of the leverage effect of the EU research programmes into the NEMESIS model:

1. What should be concluded from the existing studies on the effectiveness of national R&D subsidies in Europe?
2. In what way does additionality from European R&D support differ from national public R&D subsidies?

The first question was studied in the literature as (1) the direct support for R&D in private sector (subsidy) and (2) the R&D tax rebates; here we focus on the former as EU research programmes do not use tax rebates as R&D incentive. Furthermore, the literature mainly studied at the existence or not of the additionality effect *i.e.* by testing the hypothesis of existing input additionality without

³In the literature, the leverage effect is generally called “*input additionality*” effect in opposition to “*output additionality*” that we call economic performance.

trying to estimate its size. So when quantitative figures have been provided, two main measures have been reported:

- Elasticity (or semi-elasticity), *i.e.* changes in percentages of R&D if the subsidy rate increases by a certain percentage. A large number of the studies use this measure.
- The leverage effect (or “*bang-for-the-buck*”) *i.e.* by how many units R&D increases per unit of subsidy received. A few studies reports this measure.

Without going into the details in the literature, using Wintjes and Mohnen (2018, [333]) we can summarize the results as follows:

- Before 2000, the studies mostly reported relatively heterogeneous results but their methodology was questioned (Endogeneity Problems, David *et al.*, 2000, [93]).
- After 2000, a majority of studies on European countries found a crowding-in effect, even though there are studies that find evidence of crowding-out (Zúñiga-Vicente *et al.*, 2014, [338]).
- There is evidence of a crowding-in effect but no evidence for a substantial effect. Based on recent meta-studies and individual ones, we estimate the size of the leverage effect on private R&D expenditure to be about 0.1 (*e.g.* Dimos and Pugh, 2016, [100]). Then, 1 € of public R&D subsidy generates 0.1 € additional private R&D expenditure (1.1 € of total R&D expenditure).

The answer to the second question is even more difficult than the one to the first as there is little literature on the subject as it has more frequently studied output additionality (economic performance) rather than input additionality. Despite, this lack of evidence, we can nevertheless conclude that:

- The results on the direct additionality of European and FP support for innovation input (or output) do not all show superior positive results for EU funding compared to national funding. The direct input additionality seems to be the same or only slightly higher than 0.1 for national programmes.
- The research is more “*cutting-edge*”, more international, and more co-operative; its results take time to materialize into innovations, sales and economic effects; but these effects seem more lasting and generate more international spillovers. In other words, the indirect additionality effects seem higher than in national programmes.

- Several indications exist for complementarity between European and national R&D funding schemes. It appears that firms do research in FP and exploit this in regional and nationally supported programmes.

Table 6.2.2 – Summary of estimated FP7 effects on R&D budget growth and leveraged funds by TRL

	Estimated FP7 effect on research unit R&D budget growth (in point of percentage)			Estimated FP7 leveraged funds (in Euro per FP Euro received)		
	Non-FPR&D budget growth			Non-FP R&D budget		
	Lower boundary of the effect (2.5th percentile)	Mean effect	Higher boundary of the effect (97.5th percentile)	Lower boundary of the effect (2.5th percentile)	Mean effect	Higher boundary of the effect (97.5th percentile)
Applied research and development (TRL 4 to 9)	-1 p.p.	21 p.p.	45 p.p.	-0.01	0.06	0.14
Basic research (TRL 1 to 3)	-93 p.p.	-48 p.p.	-6 p.p.	-0.41	-0.19	-0.005

Note: Lower and higher boundaries show the range between which we are confident (at 95% level) that the true estimate on the beneficiary population lies. If the range includes the value ‘zero’, then the effect is not statistically significant at 95% confidence level.

Source: PPMI estimates from ‘high quality research units’ representative survey.

The last main source of information to quantify the leverage effect of EU research programmes is based on the study of the assessment of the European Added Value of the EU research programmes (PPMI, 2017 [272]). In this study, a large survey gathered data from FP7 participants and similar non-funded applicant units, allowing after consistent data treatment, the construction of a counterfactual analysis. This survey can be used to deepen the analysis of the results regarding the impacts of the EU research programmes on the budget of research units, in order to investigate which types of participants saw a higher increase in R&D budget as a result of their participation in FP7. The two main factors explored here are:

- whether the participating organization is public or private, and
- the reported Technology Readiness Level (TRL) of their main innovation during the project that meant it was classified “Applied research and Development” and “Basic research”.

The main findings can be summarized as follows:

- The impact of FP7 in terms of leverage was more beneficial for research units producing applied research and development of innovations than for those performing basic research.
- The impact of the FP7 on the non-European budget growth of the research units doing “*applied research and development*” is positive and estimated at +21 pp on average compared with non-FP7 grant research units. Thus, the leverage effect for these research units is estimated at 0.06, on average, with a lower bound at -0.01 and a upper bound at +0.14.
- The impact of the FP7 on the non-European budget growth of the research unit doing “*Basic research*” is negative and estimated at -48 p.p on average compared with non-FP7 grant research units. Thus, the leverage effect for these research units is estimated at -0.19, on average, with a lower bound at -0.41 and a upper bound at -0.005.

Direct vs indirect leverage effect

A last important point regarding these sources of information is the relatively short-term analysis that they perform. Almost all studies do short-term analysis but “*empirical evidence suggests that the effect of public subsidies on private R&D needs not be instantaneous and can be distributed over a longer span of time, so short-term and long-term effects might differ*” (Zúñiga-Vicente et al., 2014, *ibid*). Thereby, in NEMESIS we take into account two kind of leverage effects:

- The direct leverage effect that is defined with the help of the empirical analysis presented above.
- The indirect leverage effect assuming that firms keep their investment effort in research in the long term constant. This means that the R&D expenditures of a firm are assumed, in the long-term, to grow at the same rate as its production or its turnover. This last assumption seems reasonable, as besides the relative costs of the production factors, this “accelerator effect” of the level of economic activity on the investment decision of firms, has long been established from a long time in production theory. For research performed by public organizations, we similarly retain an unitary indexation of research expenditures on the growth of GDP, assuming a constant share of the research budget in each member states public budget.

6.2.2.2 Knowledge spillovers

The knowledge spillovers are multidimensional in NEMESIS and are calculated in the inter-sectorial (*i.e.* between economic sectors) and international (between countries) dimensions simultaneously (see

chapter 5). Their modeling involves numerous technical coefficients (more than 750,000 for R&D) that are the basis to measure the knowledge flows between countries and sectors in NEMESIS.

There are no general assessments of the knowledge spillovers specific to EU research Programmes and we have not modified the knowledge spillover mechanisms of the model for the interim assessment of H2020. Nevertheless, as the FP modify R&D expenditures, one of their main channels of impact is the new knowledge they contribute to produce and diffuse as a positive externality between sectors and countries. This will therefore materialize in the model as positive economic impacts, from which the specific contribution of the new knowledge provoked by the FP can be quantified.

6.2.2.3 Economic performance

The economic performance measures the transformation of knowledge in marketable innovations that transform into different economic outcomes: employment, exports and competitiveness, increased production, value-added and GDP. Other indicators also allow for the calculation of the performance of the knowledge generated in terms of different social and environmental indicators. Economic performance is already a functional component of the NEMESIS model that is calibrated on the basis of the available literature (Stiroh, 2002 [305]; O'Mahony and Vecchi, 2005 [258], Hall et al., 2009 [155], Niebel et al., 2013 [250] , or Kancs and Siliverstovs, 2016 [192]). The calibration is made by country and sector with values taken from the consensus in the applied literature (see chapter 5).

In the case of the socioeconomic impacts of the European research programmes, the question is how to evaluate their European Added-Value (EAV), when compared to other research activities and especially national ones. The main problem is to quantify the marginal economic performance of the European research programmes, or in other words, how European research is performing compared with to general research activities. There is a relative consensus in the literature on the positive EAV of European research, but a precise quantification of this positive EAV is more difficult. For the most part, the literature focusing on EAV of the European Research Programmes is based on surveys, bibliometric analysis and sometimes on patent analysis (Rosenberg et al.; 2016 [285]; Vullings *et al.*; 2014, [331]; Delanghe et al., 2007 [98]) . From this literature, the previous assessment of the over-performance of the European Research programmes compared with national ones was fixed at 7% for FP7 and 15% for H2020 (EC, 2012, Annex 5, [115]). But, new evidence, from PPMI (2017, *ibid*), suggest that 15% is a conservative assumptions, as:

- Firstly, for FP7, comparing SJR (Scientific Journal Ranking) it appears that the publications

produced in FP projects were published in more important journals than non-FP publications published by the same authors who participated in EU-funded projects during 2007-2015. This represents an higher scientific impact of about +21%.

- Secondly, according to the analysis of FP7 survey data, the EU FP research teams were around 40% more likely to be granted patents or produce patent applications: 25% of funded research units produced at least one IPR output in 2015 compared to 18% for non-funded units.
- Thirdly, for FP7, patent analysis shows that the patents produced in the FPs were of higher quality and more likely to be of commercial value than similar patents produced elsewhere. One of the most often used indicators for a patent's value is the number of citations it received in other patents and this analysis found that FP7 patents were cited significantly more than the control sample (randomly selected non-FP sample) with an higher score of about +70%.
- Fourthly, FP7 patents cited non-patent literature +11% more often than non-FP patents suggesting that FP patents are likely to be of higher technological value and more likely to be based on cutting-edge scientific knowledge.

All these results were obtained for FP7 beneficiaries, as there are not yet sufficient data available for H2020 to estimate its performance in terms of scientific and commercial outputs. Furthermore, it takes time for R&D and scientific knowledge to become innovation and to produce substantial economic revenues. Therefore, additional time will be necessary to accurately assess the commercialization results of the projects financed by the FP7. The important point is that all the elements above confirm that there is a positive EAV of European research and a value of 15% could appear conservative as this micro evidence would globally set it at level superior to 20%. Nevertheless, as more confirmation is needed, it seems preferable to assume that the economic performance of the research activity at EU level will be 15% higher than research activities performed at national level.

6.2.3 The reference scenario

Finally, this sub-section briefly presents the general characteristics of the “*reference scenario*” of the NEMESIS model that served as basis to quantify the SEEI of H2020. The reference scenario was based on the extrapolation of past trends and various forecasts for the medium and long term made by the DG ECFIN and notably the EPC/DG ECFIN 2015 Ageing Report for the long term. The overall dynamic of this scenario can be split into two phases (see table 6.2.3). In the medium term, up to

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2020-2025, Europe comes to the end of the period of crisis. After that, in the long term, the decline of the labor force, combined with moderate labor productivity growth, leads to a lower long-term growth path than that just after the crisis.

The period between 2015 and 2025 is characterized by the revival of internal demand and the main contributors to GDP are private consumption and gross fixed capital formation. After 2025, the trade balance is negatively impacted by the deterioration of competitiveness with an increase in real wages that is higher than the rise of labor productivity. This is mainly due to the reduction of unemployment and to the influence of the labor supply shortage on the long-term growth potential.

Finally in the reference scenario, the intensities of innovation assets (R&D, ICT and other intangibles) are kept constant at sectorial level from 2014 to 2050 (table 6.2.4). They decrease slightly at macro-EU level with the evolution of the sectorial composition of the economy and the increasing contribution of service industries to EU GDP up to 2050. They nevertheless remain roughly stable with a global intensity in innovation assets passing from 5.4% of EU GDP in 2014 to 5.2% in 2050.

Table 6.2.3 – The evolution of EU-28 GDP in the NEMESIS reference scenario

	2017-2020	2021-2025	2026-2030	2030-2050
	<i>Average annual growth rate (%)</i>			
EU real GDP	1.9%	1.7%	1.5%	1.4%
	<i>Contribution to EU GDP growth (annual average in GDP pt)</i>			
Private consumption	0.8%	0.9%	0.9%	0.9%
Gross fixed capital formation	0.5%	0.4%	0.4%	0.4%
Trade balance	0.3%	0.2%	0.1%	0.0%
Public consumption	0.2%	0.2%	0.2%	0.2%

Source: NEMESIS model

Table 6.2.4 – Evolution of innovation asset intensities in the NEMESIS reference scenario (in % of GDP)

	2007	2014	2020	2030	2050
	<i>Intensity (in % of GDP)</i>				
Private R&D expenditures	1.1%	1.3%	1.3%	1.3%	1.2%
Public R&D expenditures	0.7%	0.7%	0.7%	0.7%	0.7%
ICT investments	1.2%	1.1%	1.1%	1.1%	1.0%
Other intangibles (training and software)	2.4%	2.3%	2.3%	2.2%	2.2%
Total innovation assets	5.3%	5.4%	5.4%	5.3%	5.2%

Source: NEMESIS model

6.3 Introduction of the H2020 programme in NEMESIS

For H2020, the methodology used in the interim evaluation was to compare the situation of the EU economy in the short (during the execution of the research programme), medium (about 10 years after the end of the programme) and long term (about 30 years after the end of the programme), with or without the implementation of H2020. For that, in a first step, a reference (neutral) scenario was simulated (see above), where, by assumption, EC funding for research had no influence on the macroeconomic track. Then, the H2020 budget was introduced in the NEMESIS model, based on the allocation between basic and applied research in the different Member States, observed over the period 2014-2016⁴, using CORDA data. It was therefore assumed, that the allocation observed on the first period of application of the H2020 programmes, would stay constant for the remaining of the programme, until 2020.

6.3.1 The assessed budget

The total amount of the EC contribution for 2014-2016 was 14.2 billion euros, on a total of 69.3 billion euros retained in the study for the whole 2014-2020 period (table 6.3.1). The programme started slowly, as in about two and half years only 20% of the total funding was allocated and the total amount that was actually spent on this initial period (see table 6.3.2) was even inferior (about 9.4 billion euros, 13.5% of the total H2020 budget), as the average duration of the projects that were financed was about three years according to CORDA⁵. This slow start is also an explanation for the delayed economic impacts of H2020.

⁴When this study started, the data for Horizon 2020 used did not cover the whole year 2016, but only up to August 2016 (cut-off date). They were updated progressively during the study to cover to 31st December 2016.

⁵H2020 funding will go beyond 2020 (up to 2022) as the average duration of the programmes is about 34 months. The average duration of H2020 research programmes was calculated based on the projects financed between January 2014 and August 2016. It is similar to the average duration of the projects that were financed under the FP7.

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Table 6.3.1 – The allocation of H2020 budget between basic and applied research

<i>In billion € 2014</i>	<i>EC contribution</i>				<i>Total</i>
	Basic Research	Applied Research			
		Public (No JU)	Private (no JU)	Joint Undertakings	
Total 2014-2016	5.3	4.8	3.5	0.7	14.2
Funding 2017-2020	18.9	19.5	14.1	2.7	55.2
H2020 total	24.2	24.2	17.5	3.3	69.3

Source: EC –DG RTD (based on available information from eCORDA up to end August 2016)

Table 6.3.2 – Annual allocation of H2020 (in million 2014 €)

<i>In million € 2014</i>	<i>EC annual contribution</i>	<i>Total expenditures</i>	<i>Direct leverage</i>
2014	1,575	1,813	0.15
2015	3,150	3,626	0.15
2016	4,725	5,439	0.15
2017	7,717	8,911	0.16
2018	10,709	12,382	0.16
2019	13,702	15,854	0.16
2020	13,702	15,854	0.16
2021	9,292	10,751	0.16
2022	4,729	5,471	0.16
Total	69,300	80,100	0.16

Source: Calculation based on eCORDA

Similarly, beginning with the historical data (eCORDA), we add up EC contributions for each member state to obtain the national allocation of the funds as presented in table 6.3.3.

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Table 6.3.3 – Geographical allocation of H2020 (in % of total H2020 budget)

<i>In % of the total</i>	<i>EC contribution</i>	<i>Total expenditures</i>
Germany	17.7%	18.0%
United Kingdom	16.1%	15.4%
France	11.4%	11.6%
Spain	9.9%	9.9%
Italy	8.9%	9.0%
Netherlands	8.6%	8.6%
Belgium	4.6%	4.8%
Sweden	3.6%	3.5%
Austria	3.1%	3.2%
Denmark	2.8%	2.7%
Greece	2.3%	2.3%
Finland	2.3%	2.3%
Ireland	2.0%	1.9%
Portugal	1.8%	1.8%
Poland	0.9%	0.9%
Czech Republic	0.6%	0.6%
Slovenia	0.6%	0.6%
Hungary	0.6%	0.6%
Romania	0.4%	0.4%
Estonia	0.3%	0.3%
Luxembourg	0.3%	0.3%
Cyprus	0.3%	0.3%
Slovakia	0.3%	0.4%
Croatia	0.2%	0.2%
Bulgaria	0.1%	0.1%
Latvia	0.1%	0.1%
Lithuania	0.1%	0.1%
Malta	0.1%	0.1%

Source: Calculation based on eCORDA

Finally, the sectorial allocation for each member state is based on the grandfathering principle, *i.e.* the subsidies are allocated proportionally to the R&D investments in each sector. In this way, it is assumed that the more a productive sector invests in R&D, more this sector will be able to benefit from EC funding.

Table 6.3.4 – Allocation of H2020 fund by sector (Average in EU-28)

NEMESIS sectors		Share of EC contribution received (average for EU)	NEMESIS sectors		Share of EC contribution received (average for EU)
01	Agriculture	0.4 %	16	Food, Drink and Tobacco	1.5 %
02	Coal & Coke	0.1 %	17	Textile, Clothes & Footwear	0.6 %
03	Oil & Gas Extraction	0.1 %	18	Paper & Printing Products	0.7 %
04	Gas distribution	0.1 %	19	Rubber & Plastic	1.8 %
05	Refined Oil	1.1 %	20	Other Manufacturing	0.5 %
06	Electricity	0.5 %	21	Construction	0.5 %
07	Water Supply	0.1 %	22	Distribution	3.0 %
08	Ferrous & non-Ferrous Metal Products	0.7 %	23	Lodging & Catering	0.0 %
09	Non-Metallic Mineral Products	0.6 %	24	Inland Transport	4.3 %
10	Chemicals	15.8 %	25	Sea & Air Transport	1.3 %
11	Metal Products	1.3 %	26	Other Transport Services	2.8 %
12	Agricultural and Industrial Machines	7.3 %	27	Communication	1.6 %
13	Office Machines	8.7 %	28	Bank, Finance, Insurance & Real estate	0.0 %
14	Electrical Goods	7.5 %	29	Other Market Services	17.9 %
15	Transport Equipment	19.4 %			

Source: Based on NEMESIS model data

6.3.2 Values for key parameters

By comparing the total amount of the EC contribution for 2014-2016, with the total cost of the programmes, the direct leverage effect of the EC contribution on the R&D effort of research organizations can be calculated (see table 6.3.2). The result is that each Euro financed by the EC budget has provoked an additional investment of 0.15 Euro for the period 2014-2016 (direct crowding-in effect). Nevertheless, as in Horizon 2020, the indirect costs (an important component of total project costs) are not based on the real indirect costs of participants, but are calculated as a fixed rate (25%) of real direct costs, so the crowding-in effect based on these values conservative, as it does not capture the real total costs associated with a project, which is probably higher. Another methodology for the estimate of the “real” indirect costs in H2020 has been developed with a sensitivity analysis based on these estimated indirect costs (see below). For the rest of the period, from 2017 to 2020, the same

direct crowding-in effect of the EC contribution⁶ was assumed and, for the whole H2020 programme, taking into account this direct crowding-in effect, there are about 80 billion Euros (in 2014 prices) of R&D expenditures directly provoked by EC funding. It was also assumed for this later period, that the allocation of the funding per member state was identical to the one observed at the beginning of the programme, while the split between basic and applied research was based on the allocation of the budget between the three first pillars of H2020 foreseen by the European Commission. This leads to a direct leverage effect for the whole period of H2020 of 0.16.

The last parameter to define was the economic performance of the EU research activities, compared with same activities implemented at national level. There exists a relative consensus in the literature on the positive EAV of European research but a precise quantification of this positive EAV is more difficult. The previous assumptions on the EAV of the European Research programmes compared with national ones was fixed at 7% for FP7 and at 15% for the ex-ante assessment of H2020 (EC, 2012, Annex 5, *ibid*), and we retained this last value of 15% for this interim evaluation of H2020⁷.

6.3.3 Summary of the main assumptions

The table 6.3.5 sums up the main assumptions used to implement the H2020 programme in the NEMESIS model.

Table 6.3.5 – Summary of H2020 assessment main assumptions

H2020 budget (EC contribution, in constant Euro 2014)	Direct crowding-in (Total project costs minus EC contribution per Euro of EC contribution)	Overperformance of FP7 research (compared with national research activities, %)	Average duration of FP7 projects (in months)	National allocation of funds	Sectoral allocation of funds	Repartition between Basic and Applied research
69.3	0.16	15 %	34	Historical (based on eCORDA, 2014 to mid-2016)	Grandfathering principle	Basic: 40 % Applied: 60 %

Source: Based on NEMESIS model data

⁶The direct crowding-in of the H2020 funding is various depending on the type of projects that are financed (basic or applied research), the type of funding scheme (grants versus Joint Undertakings) or the type of organization (public versus private). The 2014-2016 period is in this respect not fully representative of the split in the H2020 budget that was foreseen up to 2020 and it modifies slightly the average direct crowding-in effect that we calculated for the whole 2014-2020 period: 0.16, compared to the one calculated on the data collected in CORDA up to August 2016.

⁷See section 6.5.3 for sensitivity analysis on this parameter.

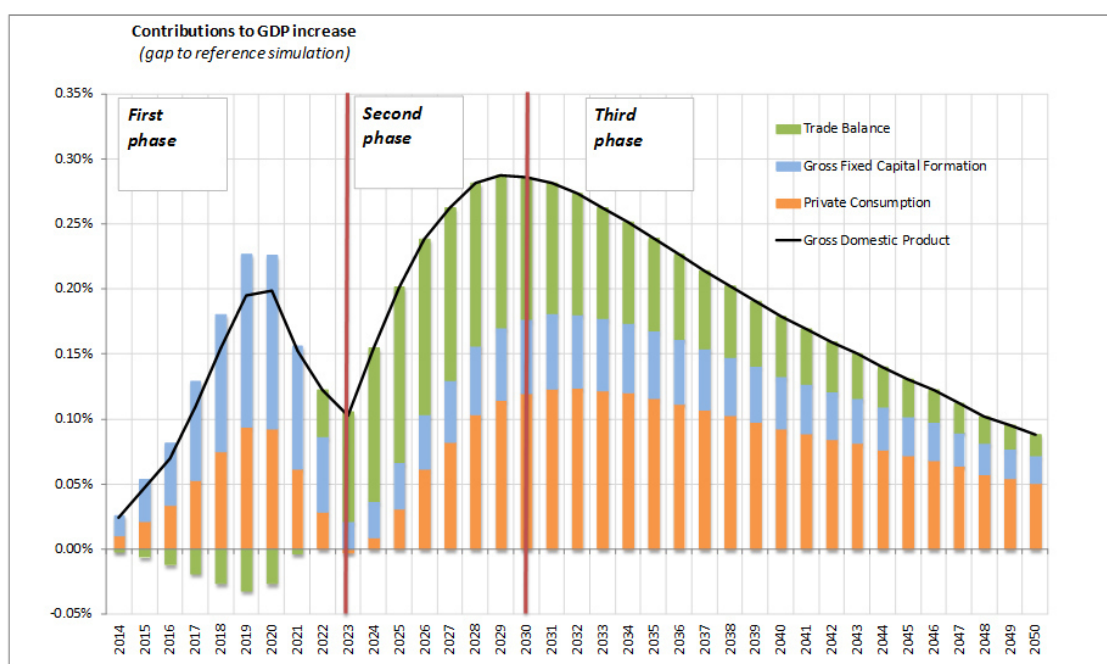
6.4 The main results of H2020 interim evaluation

6.4.1 Results at EU macro level

For EU GDP, the impacts follow three main phases illustrated by figure 6.4.1:

1. In the first phase (maturation) up to 2023 there are only a few innovations and the increase in GDP is mainly the result of the demand induced by investments in R&D through Horizon 2020. The hiring of research personal increases real wages and final consumption. The inflationary pressures deteriorate competitiveness and the increase in demand raises imports. After 2020, the reduction of the EU contribution pushes down GDP gains.

Figure 6.4.1 – The economic impact of Horizon 2020 funding for research on EU GDP (in % deviation from the reference scenario)



Source: NEMESIS model

2. During the second phase (innovation) up to 2030, the arrival of process and product innovations increases the internal and external demand. The external demand gradually becomes the main driver for GDP gains. The maximum impacts of Horizon 2020 are reached at the end of this second phase (around 2030). At its peak in 2030, Horizon 2020 is estimated as bringing a EU GDP gain of 0.29% (50 billion euros in 2014 prices) compared to the GDP of the reference

scenario.

3. During the third phase (Maturity and obsolescence), the gradual obsolescence of the new knowledge created during the previous phases, reduces the GDP gains progressively.

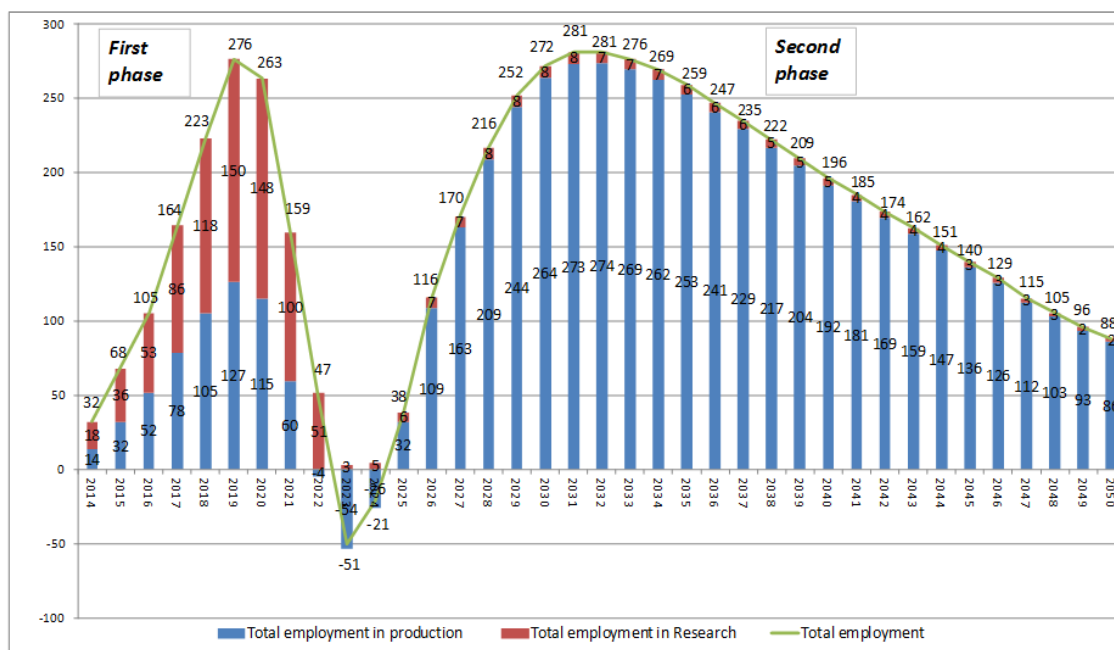
On average, the EU GDP gain is estimated at about 27 billion (2014) constant euros per year during the period 2014-2030, each Euro of H2020 budget leading to an average EU GDP increase of about 6.6 Euros⁸.

For EU employment, two phases can be distinguished (figure 6.4.2):

1. In the first phase, up to 2022, the EU contribution leads to a big increase in employment in research activities, where most of the jobs are created. Job creation peaks in 2019 when the number of jobs is 276,000 more than in the reference scenario in the same year (150,000 of them are in the research sector). Once the Horizon 2020 begins to decrease – *i.e.* beyond 2020 – employment in research comes close to zero. Innovations, that enter progressively on the market, enhance labor productivity, but the demand for the new products takes time to develop and then, for two years (2023 and 2024), total employment is slightly below its level in the reference scenario (-51,000 in 2023).
2. The second phase begins when innovations enter the market push-up job creations. In 2030, employment would amount to 272,000 jobs more than in the reference scenario, including 8,000 jobs in research.

⁸This “multiplier” effect was calculated as the sum of the EU GDP gains between 2014 and 2030 divided by the H2020 budget (69.3 billion euro prices 2014).

Figure 6.4.2 – Impact of H2020 on total employment in thousands (difference to the reference scenario)



Source: NEMESIS model

On average, for the period 2014-2030, the EC contribution will increase the level of employment by 137,000, including 48,000 in research.

The study brings many additional findings at EU macro level, as for 2030:

1. The “social rate of return of the EC contribution” will amount to 30%⁹;
2. The investments in research provoked by H2020 will increase labor productivity by 0.2%;
3. The impact of H2020 on EU external competitiveness is important, increasing net exports by about 19 billion euros;
4. The final energy consumption by unit of GDP would decrease by 0.15% and energy-related CO₂ emissions (by unit of GDP) by 0.15%, in H2020 programmes.

⁹The social rate of return was calculated as the rate that equalizes the actualized sum of GDP gains to the actualized sum of the H2020 contributions. It increases slightly in time as the annual GDP gains stay positive in most countries up to 2050, while the EC contribution stops after 2022. This 30% rate of return is in line with the econometric literature results (cf. Hall, Mairesse and Mohnen, [155]).

6.4.2 Results at EU sectorial level

On the sectorial level the results are also contrasted, depending on the phase:

1. During the first phase (Maturation), the value added gains are concentrated in the service sectors and in the sectors the less exposed to international competition such as construction (table 6.4.1). The inflationary pressures on the contrary penalize industrial and R&D intensive sectors, that encounter losses on their export and national markets (table 6.4.2).
2. During the second phase (Innovation), the gradual arrival of process and product innovations re-enforces the external competitiveness of industrial sectors. This is particularly the case for the R&D intensive sectors such as “Chemicals”, “High-Tech Industries” and “Transport Equipment” that over-perform and concentrate more than 50% of the gains on export markets that reach a maximum of 22.1 billion euros (prices 2014) in 2026 at EU level
3. During the last phase (Maturity and obsolescence), the value-added gains spread more homogeneously between sectors, as there are large productivity transfers between sectors, and notably from R&D intensive industrial sectors towards service sectors, such as transport and communication services. These productivity transfers reflect the improvement of the capital goods used by these sectors (see table 6.4.3).

Table 6.4.1 – Estimated impact on EU sectorial value-added (in % difference from the reference scenario)

	2016	2018	2020	2025	2030	2050
- Agriculture	0.04%	0.10%	0.13%	0.16%	0.28%	0.09%
- Utilities	0.03%	0.06%	0.09%	0.04%	0.19%	0.07%
- Heavy Industries	0.03%	0.07%	0.09%	0.27%	0.37%	0.10%
- Chemicals	-0.11%	-0.19%	-0.09%	1.13%	0.64%	0.12%
- High Tech. Industries	-0.05%	-0.08%	0.00%	0.99%	0.65%	0.14%
- Transport Equipment	-0.08%	-0.15%	-0.06%	1.32%	0.75%	0.15%
- Other Industries	0.05%	0.11%	0.14%	0.28%	0.37%	0.10%
- Construction	0.06%	0.13%	0.15%	0.10%	0.23%	0.08%
- Distribution	0.05%	0.11%	0.13%	0.11%	0.26%	0.09%
- Transport	0.03%	0.06%	0.11%	0.38%	0.49%	0.12%
- Communication	0.04%	0.10%	0.12%	0.11%	0.28%	0.10%
- Bank, finance, insurance	0.05%	0.11%	0.13%	0.09%	0.23%	0.08%
- Other market services	0.05%	0.12%	0.16%	0.20%	0.33%	0.11%

Source: NEMESIS model

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Table 6.4.2 – Estimated impact on EU sectorial net exports (Million euros, difference from the reference scenario)

	2016	2018	2020	2025	2030	2050
- Agriculture	-20	-47	-55	251	234	46
- Utilities	-83	-183	-194	639	504	96
- Heavy Industries	-60	-138	-131	1061	1069	225
- Chemicals	-250	-554	-530	3271	2384	474
- High Tech Industries	-472	-1108	-1245	5620	4349	822
- Transport Equipment	-211	-481	-494	2838	2144	423
- Other Industries	-188	-440	-486	2276	2059	357
- Construction	-23	-54	-70	138	98	5
- Distribution	-38	-85	-76	655	692	156
- Transport	-77	-180	-172	1695	2050	533
- Communication	-25	-62	-81	133	90	-17
- Bank, finance, insurance	-60	-151	-177	1090	1182	254
- Other market services	-102	-216	-156	1873	1940	429
- All sectors	-1640	-3773	-3948	21812	19032	3833

Source: NEMESIS model

Table 6.4.3 – Estimated impact on EU sectorial labour productivity (in % difference from the reference scenario)

	2016	2018	2019	2025	2030	2040	2050
- Agriculture	0.03%	0.08%	0.09%	0.14%	0.22%	0.14%	0.06%
- Utilities	0.00%	0.00%	0.00%	0.03%	0.11%	0.07%	0.03%
- Heavy Industries	0.00%	0.01%	0.02%	0.21%	0.13%	0.05%	0.02%
- Chemicals	-0.21%	-0.37%	-0.39%	1.14%	0.30%	0.04%	0.01%
- High Tech Industries	-0.15%	-0.28%	-0.31%	0.90%	0.32%	0.09%	0.05%
- Transport Equipment	-0.22%	-0.43%	-0.48%	1.40%	0.49%	0.13%	0.06%
- Other Industries	0.01%	0.02%	0.02%	0.19%	0.11%	0.03%	0.01%
- Construction	0.02%	0.03%	0.03%	0.08%	0.07%	0.02%	0.01%
- Distribution	0.01%	0.03%	0.04%	0.08%	0.08%	0.04%	0.02%
- Transport	-0.01%	0.01%	0.03%	0.44%	0.34%	0.11%	0.04%
- Communication	0.00%	0.01%	0.01%	0.13%	0.24%	0.14%	0.07%
- Bank, finance, insurance	0.01%	0.02%	0.02%	0.05%	0.04%	0.01%	0.00%
- Other market services	-0.02%	-0.03%	-0.03%	0.19%	0.21%	0.11%	0.06%

Source: NEMESIS model

For employment, job creation is concentrated in service sectors that represent about 70% of jobs today. In relative terms the H2020 funding for research nevertheless favors industrial employment, and notably high skill labor, in all the phases. While industrial employment represents today only 15% of total employment, about 20% of job creations provoked by EC funding will occur in industry during the first phase, 35% during the second phase and 25% during the third phase (see table 6.4.4).

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Table 6.4.4 – Estimated impact on EU sectorial employment (in thousands, difference from the scenario)

	2016	2018	2020	2025	2030	2050
- Agriculture	1	2	3	2	5	1
- Utilities	1	2	2	0	2	1
- Heavy Industries	2	4	4	4	15	4
- Chemicals	2	3	2	0	5	1
- High Tech Industries	7	14	15	6	21	4
- Transport Equipment	4	9	9	-2	7	2
- Other Industries	6	13	16	12	34	9
- Construction	8	18	24	2	28	12
- Distribution	13	27	33	9	54	15
- Transport	2	4	2	-4	10	4
- Communication	1	3	3	-1	1	1
- Bank, finance, insurance	5	11	16	4	25	12
- Other market services	31	67	77	4	61	23
- Non-market services	22	46	57	1	2	1
- Total	105	223	263	38	272	88

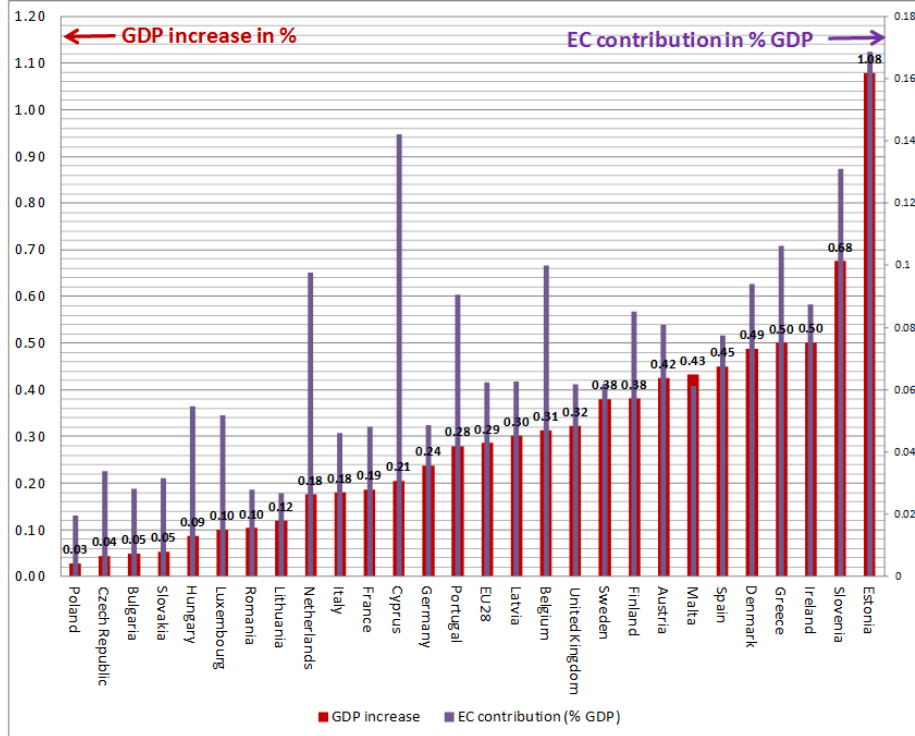
Source: NEMESIS model

6.4.3 Results at national level

At national level, the relative performance is in phase with the share of the EC funding received by the different countries (figure 6.4.3). Countries that receive very low amounts, such as Poland, encounter positive but limited impacts on GDP and employment. While some countries lose in relative competitiveness on the EU market, knowledge and productivity spillovers received from other EU countries allow them to increase their market share on the world market. External trade therefore plays an important role on the final result.

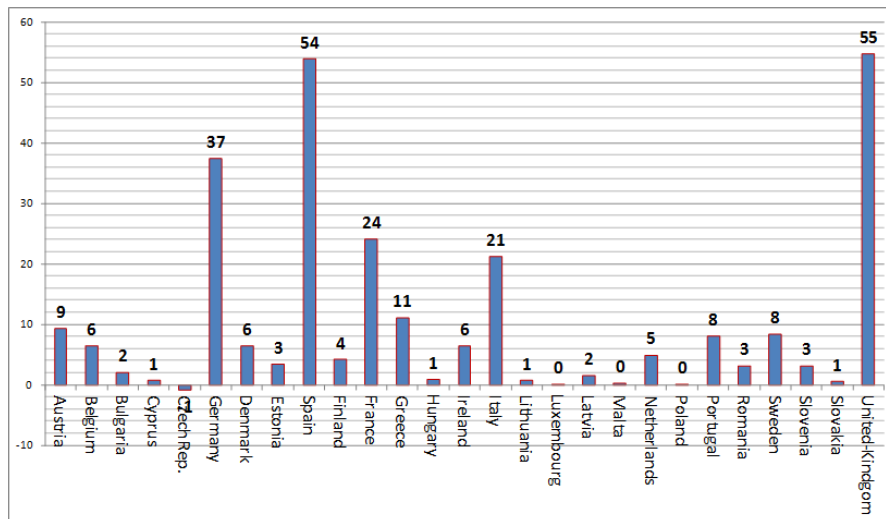
The employment results (figure 6.4.4) in 2030 show that due to the labor productivity gains provoked by innovations, the significant impact of EC funding for research on national employment is only possible when the GDP gains reach a high level. Therefore in countries like the Czech Republic, Hungary, Malta, Poland or Slovakia, employment creations are very limited, or even slightly negative like in the Czech Republic. More than 70% of jobs at EU level in 2030 are concentrated in the larger EU countries (Germany, Spain, France, Italy, UK) that receive the greatest part (64% in all) of EC contribution for research.

Figure 6.4.3 – Impact on GDP in 2030 at country level (in % deviation from the reference scenario, on the right axis) and EC contribution received (in % GDP, mean value over 2014-2020, on the left axis)



Source: NEMESIS model

Figure 6.4.4 – Impacts on total employment in the different EU countries in 2030 (thousands, in difference from the reference scenario))



Source: NEMESIS model

Table 6.4.5 finally measures both the knowledge growth and its origin in each member state and the main results for 2030 are the following:

1. The growth of knowledge at EU level is about 0.6% like in the five larger EU countries quoted above, that receive the greatest part of the EC contribution. In these countries, knowledge growth comes from relatively equal contributions from national and foreign sources (i.e. from externalities received from other EU countries). The contribution to the new knowledge from intra- and inter-sectorial sources are also quite balanced.
2. The growth of knowledge in the smaller EU countries, with a low R&D intensity, is close to the EU average. In these countries the origin of knowledge growth mainly comes from the externalities received from other EU countries, as for the Czech Republic, Bulgaria, Cyprus, Hungary, Lithuania, Latvia, Malta or Romania. Knowledge spillovers between EU countries are therefore a powerful channel for sharing the positive impact provoked by the EC contribution in every EU countries.

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Table 6.4.5 – The impact of H2020 on knowledge at country level in 2030 (in % deviation from the reference scenario)

	Total Knowledge	Contribution to knowledge increase in %			
		National sources		Foreign sources	
		Intra sectoral	Inter sectoral	Intra sectoral	Inter sectoral
Austria	0.7%	20%	19%	28%	32%
Belgium	0.8%	28%	33%	17%	22%
Bulgaria	0.2%	4%	9%	12%	76%
Cyprus	0.6%	1%	8%	11%	79%
Czech Republic	0.6%	5%	7%	60%	28%
Germany	0.6%	19%	20%	33%	29%
Denmark	0.8%	26%	29%	14%	31%
Estonia	0.6%	11%	22%	21%	46%
Spain	1.2%	32%	26%	28%	14%
Finland	0.6%	12%	24%	24%	40%
France	0.6%	28%	23%	21%	27%
Greece	1.3%	18%	36%	18%	28%
Hungary	0.6%	11%	15%	34%	40%
Ireland	0.7%	26%	26%	23%	24%
Italy	0.6%	23%	20%	31%	26%
Lithuania	0.0%	1%	5%	26%	68%
Luxembourg	0.3%	5%	5%	39%	50%
Latvia	0.4%	3%	10%	3%	83%
Malta	0.4%	1%	4%	4%	91%
The Netherlands	0.7%	27%	25%	19%	29%
Poland	0.5%	18%	27%	16%	40%
Portugal	0.9%	16%	37%	17%	29%
Romania	0.5%	3%	9%	18%	70%
Sweden	0.6%	15%	20%	35%	30%
Slovenia	0.5%	15%	29%	19%	37%
Slovakia	0.8%	7%	7%	19%	67%
The United-Kindgom	0.6%	22.9%	32.6%	16.6%	27.9%

Source: NEMESIS model

6.4.4 Summary table

Table 6.4.6 summarizes, for year 2030, the first key findings of the NEMESIS model for this interim evaluation of the H2020 programme.

Table 6.4.6 – Brief overview of key H2020 interim quantification produced by NEMESIS

Indicators/aspects of EAV	Estimated impacts
Return on investment based on financial leverage (€ of 2014)	
Estimated amount of additional leverage (direct and indirect) attracted to R&D (Sum from 2014 to 2030).	19.4 Billion
Estimated amount of direct leverage (Total cost of projects/Total H2020 budget) attracted to R&D per each euro spent in FPs (Average).	0.16 €
Estimated amount of additional leverage (direct and indirect) attracted to R&D per each euro spent in FPs (Average).	0.28 €
Economic impact of market innovations in terms of net exports (€ of 2014)	
Impact of FPs on net exports (compared to the reference scenario in 2030)	19 Billion
Multiplier effect of FP funding on the amount of net exports (Sum of net exports between 2014 and 2030 divided by sum of EC contribution)	2.1 €
Direct and indirect job creation	
Average employment gain provoked by H2020 between 2014 and 2030 (average annual change of total employment compared to its level in the reference scenario)	Total: 137 000 High-skilled: 57 000 Low-skilled: 80 000
Average employment gain in research provoked by H2020 between 2014 and 2030 (average annual increase of total employment in research compared to its level in the reference scenario)	Total: 48 000 Researchers: 29 500 Other: 18 500
Return on investment based on monetised resource savings (per unit of GDP)	
Primary energy consumption (total) (% difference from the reference scenario in 2030)	-0.1 %
Final energy consumption (total) (% difference from the reference scenario in 2030)	-0.15 %
Energy related CO ₂ emissions (% difference from reference scenario in 2030)	-0.15 %
Cost-benefit analysis of the intervention	
Estimated increase in GDP per each euro spent by Commission in FPs (Sum of GDP gains between 2014 and 2030 divided by sum of EC contribution)	6.6 €
Estimated increase in GDP per each euro spent in FP projects (Sum of GDP gains between 2014 and 2030 divided by sum of total cost of projects)	5.7 €
Internal Rate of Return of EC contribution (IRR) (This is the actualisation rate that cancels the benefits of the intervention calculated in 2030. The GDP provoked by the Keynesian effects of research expenditures were removed from the calculus)	30 %
Other economic impacts	
Total estimated effect of FPs on GDP (compared to the reference scenario in 2030, euro 2014)	50 Billion
Estimated impact of FPs on households' final consumption (compared to reference scenario in 2030, euro 2014)	21 Billion
Estimated impact of FPs on total investment (compared to the reference scenario in 2030, euro 2014)	10 Billion
Estimated change in the Labour Productivity indicator (% difference from the reference scenario in 2030)	0.2 %
Estimated effect of FPs on international competitiveness of European countries measured by:	19 Billion
- External trade balance (compared to the reference scenario in 2030, euro 2014)	-0.29 %
- Terms of trade (% difference to the reference scenario in 2030)	

6.5 Sensitivity analysis of H2020 results

The assessment of the economic impacts of H2020 presented above can be considered as rather “*conservative*” for two reasons. On the one hand, the assumption that the economic performance of the R&D funded by the EC FP is only 15% higher than the performance of national research was challenged by the micro analysis performed in the ex-post impact assessment of FP7 (see PPMI, 2017, [272]). A more optimistic value of +21% could therefore also be considered. On the other hand, the 0.16 direct crowding-in effect of H2020 funding, based on the historical data (CORDA) for the projects financed between the beginning of 2014 and August 2016, may also seem too conservative. This is an important point, as this direct crowding-in effect is, in our assessment methodology, the most important source of difference that we observe between the H2020 and the FP7 programmes. This section therefore analyses the consequences of changing the central assumptions on the direct crowding-in effect and on the EAV of H2020 funding.

6.5.1 “*Optimistic*” and “*Pessimistic*” scenarios: assumptions

For FP7, its direct crowding-in is 0.43, from CORDA data, which is about 2.7 times superior ($0.43/0.16$) than for H2020. A major source of explanation for this difference is the different method used in the two programmes to calculate the indirect costs of the projects, an important component of total project costs. For FP7, the calculation was based on the real indirect costs declared by the participants. For H2020, the calculation of indirect costs was not based on the real indirect costs of participants, but they were calculated as a fixed rate (25%) of real direct costs: the crowding-in effect based on these values is therefore conservative, as it does not capture the real total costs associated with a project, which is higher using FP7 data.

In order to estimate the real indirect costs for Horizon 2020, the real indirect cost/direct cost ratio of FP7 beneficiaries (private companies only) was multiplied by the direct cost declared by Horizon 2020 beneficiaries (private companies only). This new calculation, that is closer to the methodology used to calculate the indirect cost in FP7, this time provides an increased value for the direct crowding-in effect for H2020, as summed up in table 6.5.1.

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Table 6.5.1 – New crowding-in assumption based on the recalculation of the indirect costs using FP7 methodology and eCORDA data

	EC contribution			Direct Crowding-in		
	Basic Research	Applied Research	Total	Basic Research	Applied Research	Total
	Previous calculation based on data available up to end August 2016 - Indirect costs : 25%					
Total 2014-2016	5.3	8.9	14.2	0.2	2.0	2.1
Funding 2017-2020	18.9	36.2	55.2	0.7	8.0	8.6
H2020 total	24.2	45.1	69.3	0.9	9.9	10.8
	New calculation based on data available up to 1st January 2017 - Indirect costs based on FP7					
Total 2014-2016	7.2	10.2	17.4	0.5	4.9	5.4
Funding 2017-2020	17.0	34.9	51.9	1.1	16.7	17.8
H2020 total	24.2	45.1	69.3	0.1	0.6	23.2

Source: Based on eCORDA data

For the first period, from the beginning of the programme in 2014 up to the 1st January 2017, the direct crowding-in for H2020 is 0.31 (5.4/14.2). So, the direct crowding-in of FP7 is only 1.3 times superior (0.43/0.31) to the crowding-in recalculated for the first period of H2020.

For the whole H2020 period, following the planned allocation between applied and basic research, the average direct leverage reaches 0.34 (23.2/69.3). The direct crowding-in for FP7 is only 27% (0.43/0.34) higher than the one recalculated for H2020.

To complement the central results presented in the previous section for the evaluation of H2020, we have therefore simulated two additional scenarios using NEMESIS.

Table 6.5.2 – Key assumptions used in the three scenarios

	Economic performance of EU R&D funds (compared with national research activity)	Direct crowding-in
“H2020” scenario	+15%	0.16
“Optimistic” scenario	+21%	0.34
“Pessimistic” scenario	+0%	0.16

In the first scenario (see table 6.5.2), called “Pessimistic”, the direct crowding-in effect used is identical to the “H2020” scenario (0.16), and we make the assumption that the research financed by the FP has the same economic performance as the research financed at a national level. This scenario is

“*Pessimistic*”, as the assumptions used for the crowding-in effect (0.16), and the economic performance (0%), are both at the lower bound of the reasonable assumptions that could be retained for these two “*parameters*”.

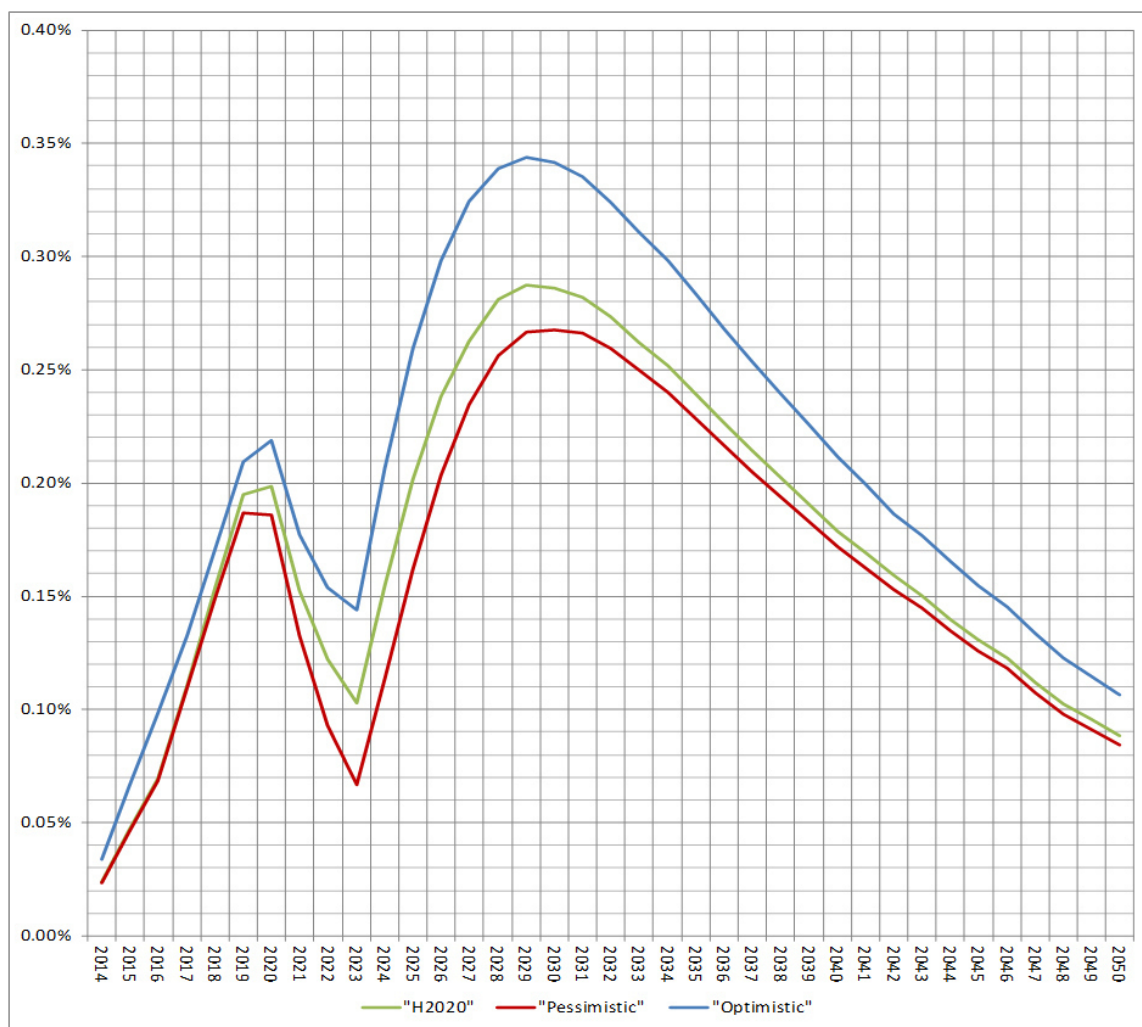
In the second scenario, called “*Optimistic*”, the values used for these two “*parameters*” were set at the higher “*acceptable*” bound. On the one hand, the economic performance of the research financed by the FP was assumed to be 21% higher than for the research financed at a national level, this value resulting from the micro analysis performed in the study by PPMI (PPMI, 2017, [272]). On the other hand, the direct crowding-in effect used was based on the new calculation of indirect costs proposed by the Commission, that were summarized in table 6.5.1.

6.5.2 The “*Optimistic*” and “*Pessimistic*” scenarios: results

For the EU GDP, changing the assumption on the economic performance of H2020 and the direct crowding-in, greatly modifies the amplitude of the impacts, with differences between the three scenarios that vary a lot according to the time horizon (see figure 6.5.1).

During the first years (up to 2020,) when the EC contribution increases but the new knowledge created had not yet produced much innovation, the impacts on GDP are quite similar between the three scenarios. They are respectively, for the year 2020, +0.19% for “*Pessimistic*”, +0.20% for “*H2020*” and +0.22% for “*Optimistic*”, for which the direct crowding-in effect is about twice as high (0.34/0.16) than in the other two scenarios.

Figure 6.5.1 – Sensitivity of EU GDP gains with the assumptions of H2020 (% deviation w.r.t. reference scenario)



Source: NEMESIS model

After 2020, the R&D expenditures provoked by the FP cease progressively, but the increase of knowledge provoked by past expenditures increasingly transforms into innovations, that begin to diffuse on the market. In 2023, the EU GDP gains are reduced in every scenario compared to the gains measured for 2020. But the reduction is smallest in “*Optimistic*” (-0.08 GDP point in 2023 compared to 2020) than in “*H2020*” (-0.1 GDP point), and larger in “*Pessimistic*” (-0.12 GDP point). While in the “*Optimistic*” scenario, the reduction of research expenditures should lead to a greater reduction of GDP (as in this scenario the direct crowding-in is higher), this negative effect is more than compensated by the higher assumption retained for economic performance (+21% against +15%): with more

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innovations GDP gains are increased. The GDP gains in the three scenarios are respectively, for the year 2023, +0.07% for “*Pessimistic*”, +0.1% for “*H2020*” and +0.14% for “*Optimistic*”.

After 2023, the EU GDP gains begin to re-increase in every scenario and remain superior in “*Optimistic*” (with the stronger economic performance), and inferior in “*Pessimistic*”, compared to “*H2020*”. The EU GDP gains reach their maximum in 2029-2030 in every scenario, with, respectively, +0.27% for “*Pessimistic*”, +0.29% for “*H2020*” and +0.34% for “*Optimistic*”.

Then after 2030, the GDP gains progressively decrease in every scenario following the progressive obsolescence of knowledge provoked by the FP.

To summarize, the EU GDP gains (and this is similar for employment) are always superior in the scenarios with the most favorable assumptions for economic performance of FP, and for the direct crowding-in effect. But the differences between the three scenarios also vary a lot depending on the time horizon. To compare the results of the three scenarios, it is therefore better to consider the differences in their cumulative impacts over time.

Table 6.5.3 – Average GDP and employment gains in the three scenarios between 2014 and 2030

	Real EU GDP gains (annual average between 2014 and 2030, in difference w.r.t. the reference scenario, in constant euro 2014)	EU employment gains (annual average between 2014 and 2030, in difference w.r.t. the reference scenario, in thousands)
'H2020' scenario: - Economic performance: +15 % - Direct crowding-in: 0.16 euro	27 billion	137
'Optimistic' scenario: - Economic performance: +21 % - Direct crowding-in: 0.34 euro	33 billion (+6 billion)	170 (+33)
'Pessimistic' scenario: - Economic performance: +0 % - Direct crowding-in: 0.16 euro	24 billion (-3 billion)	110 (-27)

Source: NEMESIS model

Table 6.5.3 compares the EU GDP gains accumulated over the period 2014-2030 divided by the number of years (17 between 2014 and 2030); the figures therefore vary the average EU GDP and EU employment gains per year for the whole period 2014-2030.

For “*H2020*”, the GDP gains are on average of 27 billion constant (2014) euros per year during the period. They reach 33 billion in “*Optimistic*” (+ 6 billion) and are limited to 24 billion in “*Pessimistic*”. For EU employment, the average annual gains were 137,000 for “*H2020*” and go up to 161,000 (+ 33,000) for “*Optimistic*” while the annual gains are limited to 110,000 (-27,000) in “*Pessimistic*”.

As a first conclusion of this sensitivity analysis for H2020, we can say that more optimistic values for the impacts of the programme on GDP and employment creation, than those measured in the “*H2020*” scenario, could be retained, with 22% higher impacts for GDP and 24% for employment. In terms of cost-efficiency, it results that the H2020 programme (69.3 billion in total in our assessment) could bring a accumulated GDP gain comprised between 406 and 558 billion euros by 2030, each euro spent by the EC leading on average between 2014 and 2030, to a GDP gain ranging from 5.9 euros in the “*Pessimistic*” case, to 8.1 EUR in the “*Optimistic*” one (see table 6.5.5).

These higher figures are nevertheless still preliminary, as they are based on the calculation of the direct crowding-in effect (0.34), on past data for FP7 programme, and for the economic performance of H2020 (+21%), on the micro works achieved in the PPMI study for FP7.

6.5.3 The results of two additional scenarios: “*Optimistic-lower*” and “*Optimistic-upper*”

The value of +21% for economic performance has strong support following the micro works created to assess the European Added value of FP7 in the PPMI study (2017, [272]). The value of 0.34 for the direct crowding-in effect of H2020 is more uncertain, as the funding scheme changed between the FP7 and the H2020 programmes, which also modified the way the European Commission accounts for indirect costs. This is anyway closer to the 0.43 direct crowding-in effect measured for FP7, based on declaration of their total costs by the project participants.

It was therefore interesting, while keeping the +21% value for economic performance, to use two alternative values for the direct crowding-in effect, and to simulate two alternative scenarios:

1. The “*Optimistic lower*” scenario, with a direct crowding-in of 0.20, that represents a more acceptable lower bound than the 0.16 value used in the “*Pessimistic*” scenario and
2. The “*Optimistic higher*” scenario, with a direct crowding-in of 0.40 that represents a new upper bound, closer to the FP7 experience.

Their results allow us to bound the additional annual average GDP gains between 2014 and 2030 (see

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table 6.5.4), compared to the “H2020” scenario, between +3 (+11%) and +8 billion (+30%) and, the employment gains, between +18,000 and +42,000 (i.e. +11% and +31% respectively). In terms of cost-efficiency, it results that with these optimistic assumptions, the H2020 programme (69.3 billion in total in our assessment) could bring an accumulated GDP gain that reaches between 503 and 589 billion euros by 2030, for each euro spent by the EC leading to an average between 2014 and 2030, of a GDP gain ranging from 7.25 euros in the “*Optimistic-lower*” case, to 8.5 euros in the “*Optimistic-upper*” one (see table 6.5.6).

Table 6.5.4 – Annual average GDP and employment gains between 2014 and 2030 following the assumption retained for the direct crowding-in effect of H2020

	Real EU GDP gains (annual average between 2014 and 2030, in difference w.r.t. the reference scenario, in constant euro 2014)	EU employment gains (annual average between 2014 and 2030, in difference w.r.t. reference scenario, in thousands)
'H2020' scenario: - Economic performance: +15 % - Direct crowding-in: 0.16 euro	27 billion	137
'Optimistic lower' scenario: - Economic performance: +21 % - Direct crowding-in: 0.20 euro	30 billion (+3 billion)	155 (+18)
'Optimistic' scenario: - Economic performance: +21 % - Direct crowding-in: 0.34 euro	33 billion (+6 billion)	170 (+33)
'Optimistic upper' scenario: - Economic performance: +21 % - Direct crowding-in: 0.40 euro	35 billion (+8 billion)	179 (+42)

Source: NEMESIS model

The table 6.5.5 and table 6.5.6 below detail finally the key quantification of economic impacts of H2020 for the “Pessimistic”, “Optimistic”, “Optimistic lower” and “Optimistic upper” scenario presented in the sensitivity analysis.

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Table 6.5.5 – Summary of key quantifications of economic impact for H2020 “Pessimistic” and “Optimistic” scenarios (in 2014 prices)

Indicators/aspects of EAV	Expected economic impact of H2020 by 2030 ('Pessimistic' scenario)	Expected economic impact of H2020 by 2030 ('Optimistic' scenario)
Return on investment based on financial leverage		
Estimated amount of additional leverage (direct and indirect) attracted to R&D (Sum from 2014 to 2030, euros 2014).	18.4 billion	32.8 billion
Estimated amount of additional leverage (direct and indirect) attracted to R&D per each euro spent in FPs (Average on 2014-2030).	0.27 €	0.47 €
Economic impact of market innovations in terms of net exports		
Impact of FPs on net exports (compared to the reference scenario in 2030, euros 2014)	18 Billion	22 Billion
Multiplier effect of FP funding on the amount of net exports (Sum of net exports between 2014 and 2030 divided by sum of EC contribution)	1.8 €	2.6 €
Direct and indirect job creation		
Average employment gain provoked by H2020 between 2014 and 2030 (average annual change of total employment compared to its level in the reference scenario)	Total: 110 000 High-skilled: 47 000 Low-skilled: 63 000	Total: 170 000 High skill: 69 000 Low skill: 101 000
Average annual employment gain in research (average annual change of total employment in research compared to its level in the reference scenario)	Total: 47 000 Researchers: 29 100 Other: 17 900	Total: 55 000 Researchers: 33 400 Other: 21 600
Return on investment based on monetised resource savings		
Primary energy consumption per unit of GDP (total) (% difference from the reference scenario in 2030)	-0.1 %	-0.11 %
Final energy consumption per unit of GDP (total) (% difference the from reference scenario in 2030)	-0.15 %	-0.17 %
Energy related CO₂ emissions per unit of GDP (% difference from reference scenario in 2030)	-0.15 %	-0.17 %
Cost-benefit analysis of the intervention		
Estimated increase in GDP per each euro spent by Commission in FPs (Sum of GDP gains between 2014 and 2030 divided by sum of EC contribution)	5.9 €	8.1 €
Internal Rate of Return of EC contribution (IRR) (This is the actualisation rate that cancels the benefits of the intervention calculated in 2030. The GDP provoked by the Keynesian effects of research expenditures were removed from the calculation)	26 %	37 %
Other economic impacts		
Total estimated effect of FPs on GDP (compared to the reference scenario in 2030, euro 2014)	46 Billion	59 Billion
Estimated impact of FPs on households' final consumption (compared to the reference scenario in 2030, euro 2014)	19 Billion	25 Billion
Estimated impact of FPs on total investment (compared to the reference scenario in 2030, euro 2014)	9 Billion	12 Billion
Estimated change in Labour Productivity indicator (% difference from the reference scenario in 2030)	0.16 %	0.19 %
Estimated effect of FPs on international competitiveness of European countries measured by:		
- External trade balance (compared to the reference scenario in 2030, euro 2014)	18 Billion	22 Billion
- Terms of trade (% difference to the reference scenario in 2030)	-0.28 %	-0.33 %

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Table 6.5.6 – Summary of key quantifications of economic impact for H2020 “*Optimistic-lower*” and “*Optimistic-upper*” scenarios (in 2014 prices)

Indicators/aspects of EAV	Expected economic impact of H2020 by 2030 ('Optimistic lower' scenario)	Expected economic impact of H2020 by 2030 ('Optimistic upper' scenario)
Return on investment based on financial leverage		
Estimated amount of additional leverage (direct and indirect) attracted to R&D (Sum from 2014 to 2030, euros 2014).	Billion 22.9 €	Billion 37.2 €
Estimated amount of additional leverage (direct and indirect) attracted to R&D per each euro spent in FPs (Average on 2014-2030).	0.33 €	0.54 €
Economic impact of market innovations in terms of net exports		
Impact of FPs on net exports (compared to the reference scenario in 2030, euros 2014)	20 Billion	23 Billion
Multiplier effect of FP funding on the amount of net exports (Sum of net exports between 2014 and 2030 divided by sum of EC contribution)	2.3 €	2.8 €
Direct and indirect job creation		
Average employment gain provoked by H2020 between 2014 and 2030 (average annual change of total employment compared to its level in the reference scenario)	Total: 155 000 High-skilled: 63 000 Low-skilled: 92 000	Total: 179 000 High skill: 72 000 Low skill: 107 000
Average annual employment gain in research (average annual change of total employment in research compared to its level in the reference scenario)	Total: 50 000 Researchers: 31 000 Other: 19 000	Total: 58 000 Researchers: 35 000 Other: 23 000
Return on investment based on monetised resource savings		
Primary energy consumption per unit of GDP (total) (% difference from reference scenario in 2030)	-0.1 %	-0.12 %
Final energy consumption per unit of GDP (total) (% difference from the reference scenario in 2030)	-0.16 %	-0.18 %
Energy related CO₂ emissions per unit of GDP (% difference from the reference scenario in 2030)	-0.15 %	-0.18 %
Cost-benefit analysis of the intervention		
Estimated increase in GDP per each euro spent by Commission in FPs (Sum of GDP gains between 2014 and 2030 divided by sum of EC contribution)	7.25 €	8.5 €
Internal Rate of Return of EC contribution (IRR) (It is the actualisation rate that cancels the benefits of the intervention calculated in 2030. The GDP provoked by the Keynesian effects of research expenditures were removed from the calculation)	33 %	37 %
Other economic impacts		
Total estimated effect of FPs on GDP (compared to the reference scenario in 2030, euro 2014)	53 Billion	62 Billion
Estimated impact of FPs on households' final consumption (compared to the reference scenario in 2030, euro 2014)	22 Billion	26 Billion
Estimated impact of FPs on total investment (compared to the reference scenario in 2030, euro 2014)	11 Billion	13 Billion
Estimated change in Labour Productivity indicator (% difference from the reference scenario in 2030)	0.17 %	0.20 %
Estimated effect of FPs on international competitiveness of European countries measured by:		
- External trade balance (compared to the reference scenario in 2030, euro 2014)	20 Billion	23 Billion
- Terms of trade (% difference to the reference scenario in 2030)	-0.29 %	-0.35 %

6.6 The “H2020 forever” scenario

To better measure the long term impacts of the EU FP funding, an additional scenario, called “H2020 forever”, was simulated. The different assessments of H2020 provided above, assume the end of the EU research programmes, and allow an evaluation of the impacts of the programme “*per se*”, but this does not portray the “*reality*” of the EU R&I support policy. Since 1984 and the 1st Framework Programme, there was no interruption in the EU research support policy, even if the budget and its implementation significantly changed. So, an H2020 scenario assuming the prolongation of the programmes after 2020, may show the long-term impacts of the policy, and avoid discontinued economic impacts as in these first assessments. The different phases (Maturation, Innovation and Obsolescence) in the economic impacts observed with the temporary shock, do not appear so clearly in this scenario, where a “*forever*” policy shock is implemented.

6.6.1 “H2020 forever” assumptions

In this new scenario, the FP is not stopped after 2020, but is prolonged up to 2050. For the post-H2020 period, it was assumed (as in the *ex-ante* assessment of H2020 (EC 2012, [115]) that the annual EC contribution is increased each year by 0.45 billion euros in constant (2014) prices. From 2014 to 2020, the evolution of the EC contribution is identical to previously but, after 2020, the increase of 0.45 billion euros each year leads to an annual EC contribution that grows from 13.7 billion in 2020, to 18.2 billion in 2030, and finally up to 27.2 billion in 2050. All the other assumptions in this scenario (see table 6.6.1), notably those concerning the allocation of the budget, the leverage effect and the economic performance of FP are the same as in the “H2020” scenario above, where the FP stops at the end of 2020.

Table 6.6.1 – Summary of “H2020 forever” main assumptions

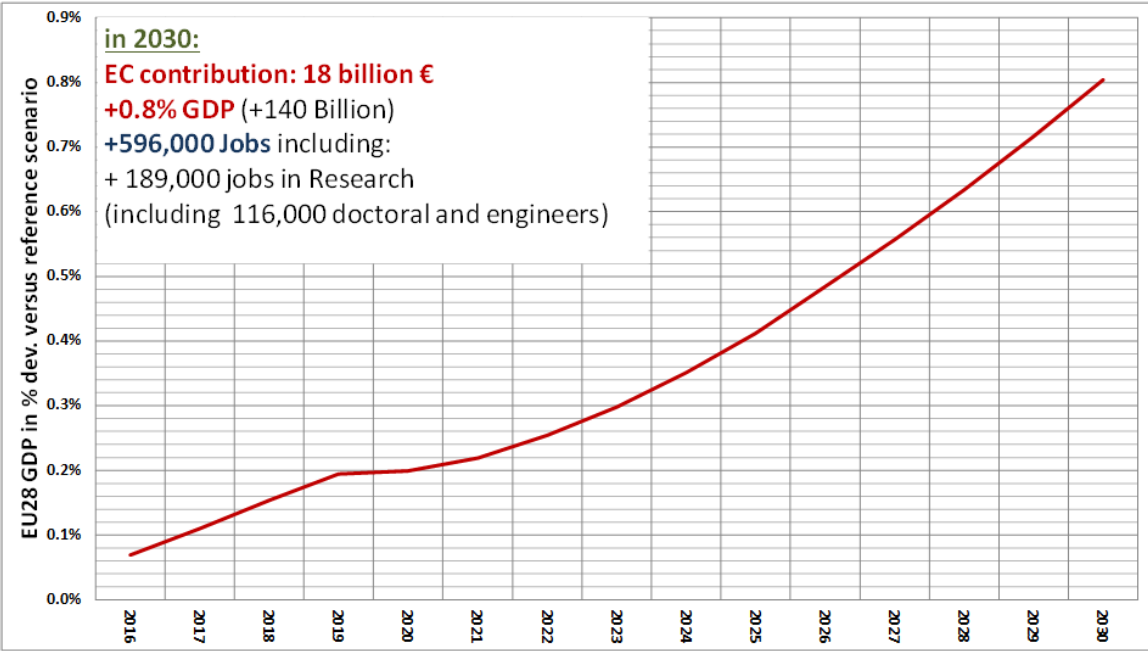
H2020 budget 2014 to 2020 (EC contribution, in constant Euro 2014)	H2020 budget after 2020 (EC contribution, in constant Euro 2014) (□)	Direct crowding-in (Total project costs minus EC contribution per Euro of EC contribution)	Overperformance of H2020 research (compared with national research activities, %)	Average duration of H2020 projects (in months)	National allocation of funds	Sectoral allocation of funds
69.3	Increase of 0.45 billion per year	0.16	15%	34	Historical (based on eCORDA, 2014 to mid-2016)	Grandfathering principle

Source: Based on EC assumptions and eCORDA data

6.6.2 Economic impacts under the “H2020 forever” scenario

The figure 6.6.1 shows that prolonging H2020 up to 2030 will lead to a EU GDP gain in 2030 of 0.80% compared with the reference scenario (140 billion euros at 2014 prices) against only +0.29% (50 billion Euros) when H2020 is stopped and not replaced after 2020. The GDP gains are therefore almost three times higher. For total employment, the gain reaches, in 2030, 596,000 jobs against 272,000 jobs in the “H2020” scenario. It represents an increase of about 324,000 jobs between the two scenarios.

Figure 6.6.1 – Results of the “H2020 forever scenario” at EU level (in % deviation w.r.t. reference scenario)



Source: NEMESIS model

At country level, the GDP gains reach up to 4% in Estonia, that benefits the most from the EC funds (in GDP points). In the long run, the prolongation of H2020 funding has a very important impact on GDP growth in EU countries. The simulation results indicate, on average between 2030 and 2050, an increase in real EU GDP growth rate of about +0.09 point per year (and of 0.05 point for the labor productivity growth rate). This increase of EU GDP growth rate reaches +0.39 point per year in the long term for Greece, +0.29 point in Estonia, +0.22 point in Slovenia and +0.21 point in Denmark. But some countries, the weakest in terms of research and innovation, may be penalized in the long term, such as Poland as well as those that benefit the lowest from FP funds (in % of their GDP) such as Luxembourg, Czech Republic or again Poland (table 6.6.2).

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Table 6.6.2 – Results for real GDP of the “H2020 forever” scenario at country level

	Real GDP change in 2030 (in % dev. from the reference scenario)	Change in annual growth rate of GDP (average between 2030 and 2050 in dev. from the reference scenario)
Austria	1.48 %	0.10 %
Belgium	1.24 %	0.10 %
Bulgaria	0.25 %	0.04 %
Cyprus	1.25 %	0.10 %
Czech Republic	0.08 %	-0.02 %
Germany	0.65 %	0.05 %
Denmark	1.36 %	0.21 %
Estonia	3.99 %	0.29 %
Spain	1.18 %	0.15 %
Finland	1.14 %	0.14 %
France	0.51 %	0.06 %
Greece	1.70 %	0.39 %
Hungary	0.38 %	0.01 %
Ireland	1.77 %	0.08 %
Italy	0.52 %	0.07 %
Lithuania	0.42 %	0.02 %
Luxembourg	0.22 %	-0.03 %
Latvia	1.25 %	0.09 %
Malta	1.40 %	0.13 %
The Netherlands	0.75 %	0.08 %
Poland	0.12 %	-0.01 %
Portugal	1.18 %	0.11 %
Romania	0.36 %	0.09 %
Sweden	1.10 %	0.12 %
Slovenia	2.54 %	0.22 %
Slovakia	0.36 %	0.02 %
United-Kindgom	0.84 %	0.11 %
EU-28	0.80 %	0.09 %

Source: NEMESIS model

6.7 Comparison of “*H2020 forever*” with the results of the *ex-ante* impact assessment

The impacts on EU GDP and employment measured in this interim assessment of the H2020 programme were compared to those of the *ex-ante* assessment made in 2012¹⁰. It should be noted that this comparison is not direct for the following reasons:

1. In the *ex-ante* assessment, it was assumed that the programme will be prolonged after 2020 up to 2030 and increased each year by 450 million Euros (2014). So the comparison must be made with the “*H2020 forever*” scenario, where the programme was similarly continued after 2020 and also increased each year by 450 million after 2020;
2. In the *ex-ante* assessment, the total budget foreseen for the 2014-2020 period was 84.9 billion euro (2014), while the outline of the H2020 budget assessed in the *interim* evaluation, was only 69.3 billion (see section 6.3.1);
3. Between the two assessments, the accounting framework changed and, from 2014, R&D expenditures are capitalized in the GDP figures. This mechanically increases the GDP in the *interim* assessment, compared to the *ex-ante* assessment where this accounting effect was not present;
4. The reference scenarios used for the two assessments are different as they were based on different economic forecasts, at different points in time.

The NEMESIS model also evolved and a new innovation module was introduced since the *ex-ante* assessment was made. To make this comparison feasible, it was therefore necessary, as a first step, to:

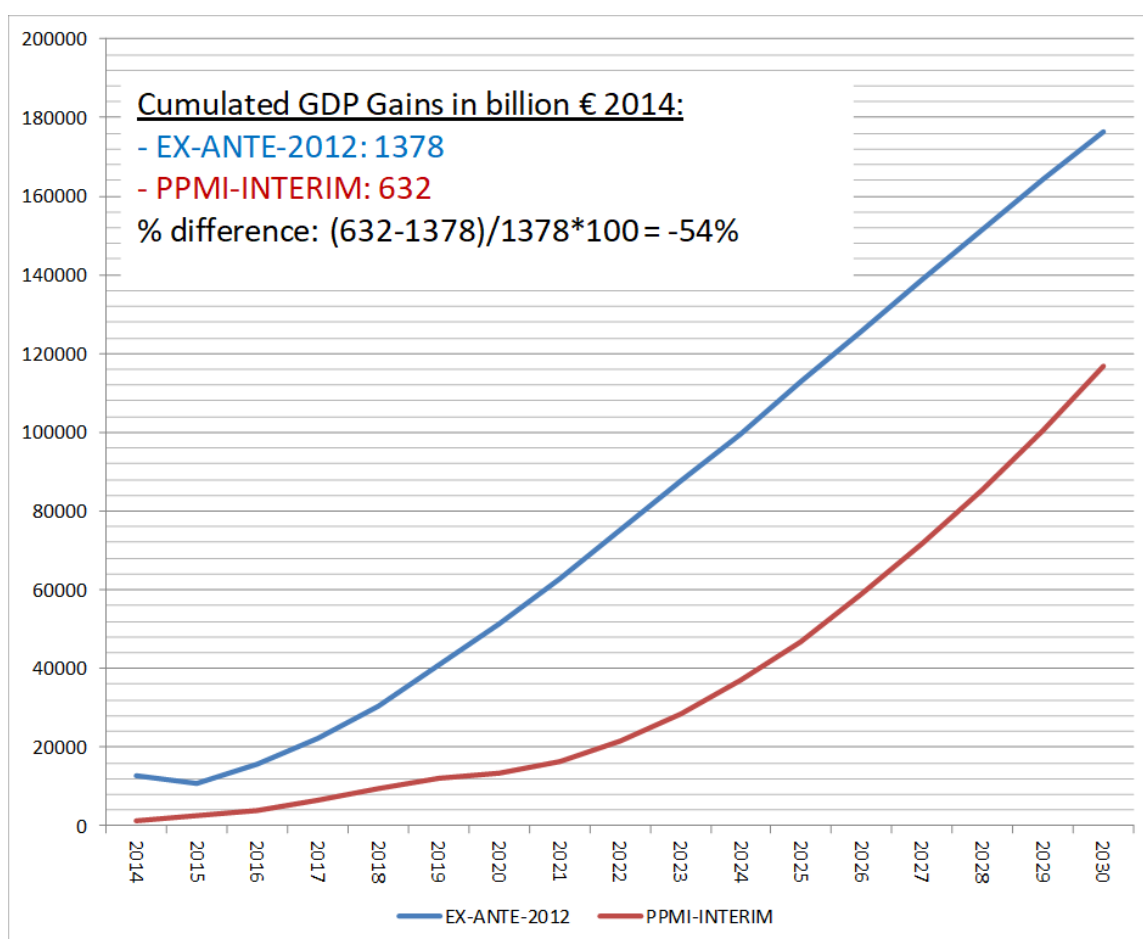
1. Suppress the capitalization of the R&D expenditures of the programme in the results of the *interim* study;
2. Recalculate the results for EU GDP and employment in the 2012 *ex-ante* assessment based on the figures in the reference scenario that was used for the *interim* evaluation. The methodology consists-in applying the results of the former 2012 assessment, in % deviation from the reference scenario of the model that was used in 2012, to the employment and GDP figures in the reference scenario used in the *interim* study.

¹⁰European Commission, 2012, “The Grand Challenge – The design and societal impact of Horizon 2020”, Directorate-General for Research and Innovation.

6.7.1 Direct comparison of the two assessments

Applying the modifications above, the figure 6.7.1 displays the annual EU GDP gains in Euros 2014 for the two assessments. By accumulating these gains over the whole 2014 to 2030 period, we see that the EU GDP gains in the *ex-ante* assessment (EX-ANTE-2012) add up to 1,378 billion Euros against only 632 billion Euros in this new study (PPMI-INTERIM). The accumulated GDP gains in “PPMI-INTERIM” are therefore 54% lower than the GDP gains calculated from the results of the *ex-ante* assessment.

Figure 6.7.1 – Comparison of GDP gains between the *ex-ante* and the interim assessments (million 2014 €, deviation w.r.t the reference scenario) (The accumulated GDP gains are the integral, between 2014 and 2030, of the annual GDP gains displayed on the graph)



Source: NEMESIS model

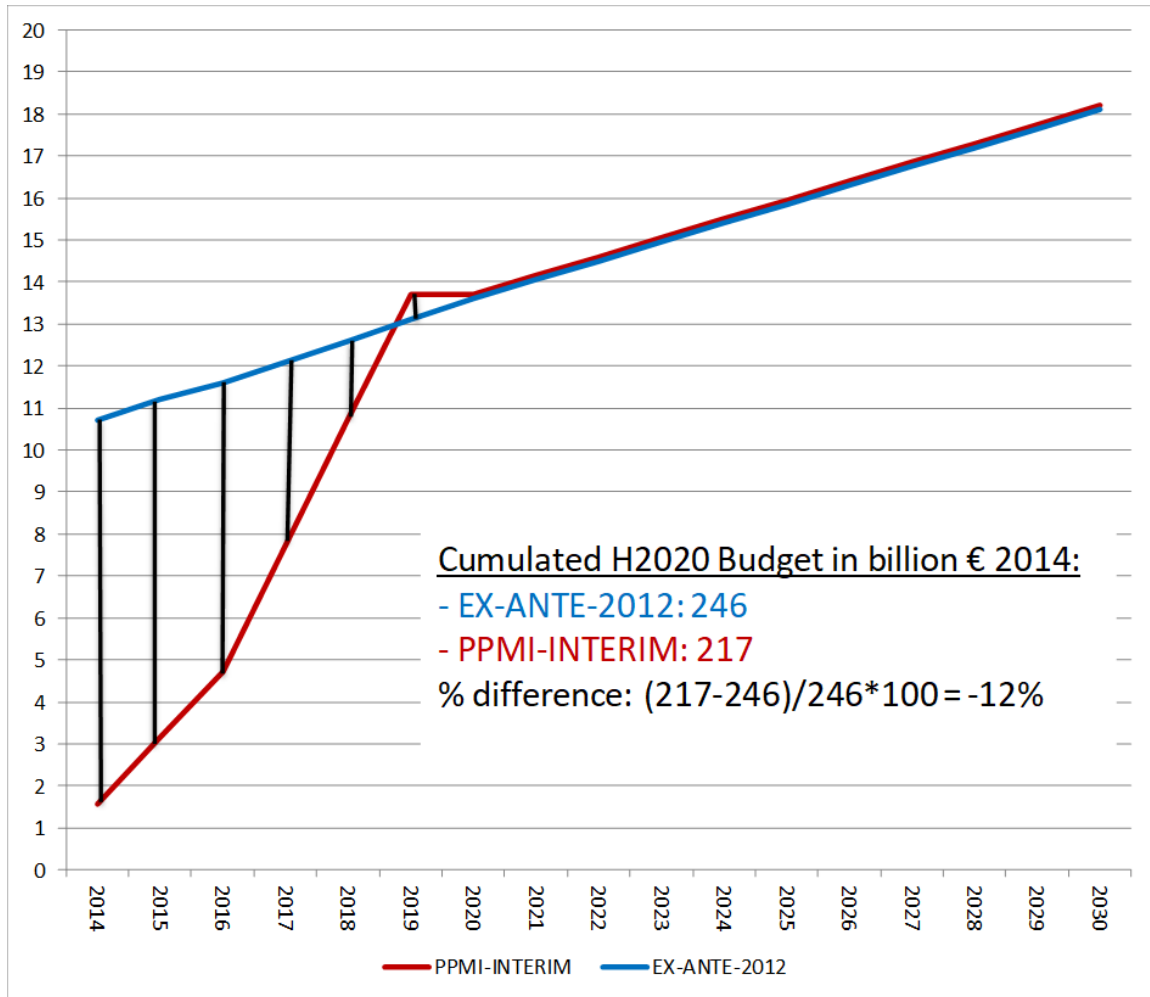
6.7.2 Explaining the difference: The role played by the size of the H2020 budget

A first explanation of this important difference between the two assessments, superior to 50%, is in the total amount of the H2020 budget that was introduced in the NEMESIS model. In the *ex-ante* assessment, the total budget introduced in the model between 2014 and 2030 equals 246 billion Euros (2014), while it was only 217 billion Euros in “*PPMI-INTERIM*”, which represents an accumulated difference of 12% in the size of the budget. While the two annual budgets are nearly the same after 2020, with an identical growth of 450 million EUR each year, there is an accumulated difference of about 29 billion euros for the period that covers the H2020 programme from 2014 to 2020.

There are two complementary explanations for this budget difference in the model:

1. The first comes directly from the outline of the total H2020 budget that was retained in the assessment. It was 84.9 billion euros in “*EX-ANTE-2012*” against only 69.3 billion in “*PPMI-INTERIM*”, a difference of 15.6 billion euros.
2. The second is the dynamic of the budget spending. In the *interim* study (“*PPMI-INTERIM*”), this dynamic was based, notably, on the budget allocated between the January 2014 and August 2016, and on the average duration of the projects that were financed during that period (34 months). A very gradual increase of the funds spent each year in “*PPMI-INTERIM*” results from this methodology. For “*EX-ANTE-2012*”, the logic behind the assessment was different. Here the FP7 budget was introduced in the reference scenario and the “*true value*” of H2020, as displayed in Figure 24 for GDP, was assessed by “(...) *comparing the positive effects of the Horizon 2020 option with the negative effects on the discontinuation option (...)*” (see p. 36, EC 2012, *ibid*). Using this methodology, the budget introduced annually in the model captured the long term dynamic of the FP funding when passing from one programme to the following one. This explains the remaining difference in the funds spent each year during the H2020 programme (2014-2020 period) between the two assessments, *i.e.* 13.4 billion euros.

Figure 6.7.2 – Comparison of the annual H2020 budget introduced in the model between the two assessments (billion euros)

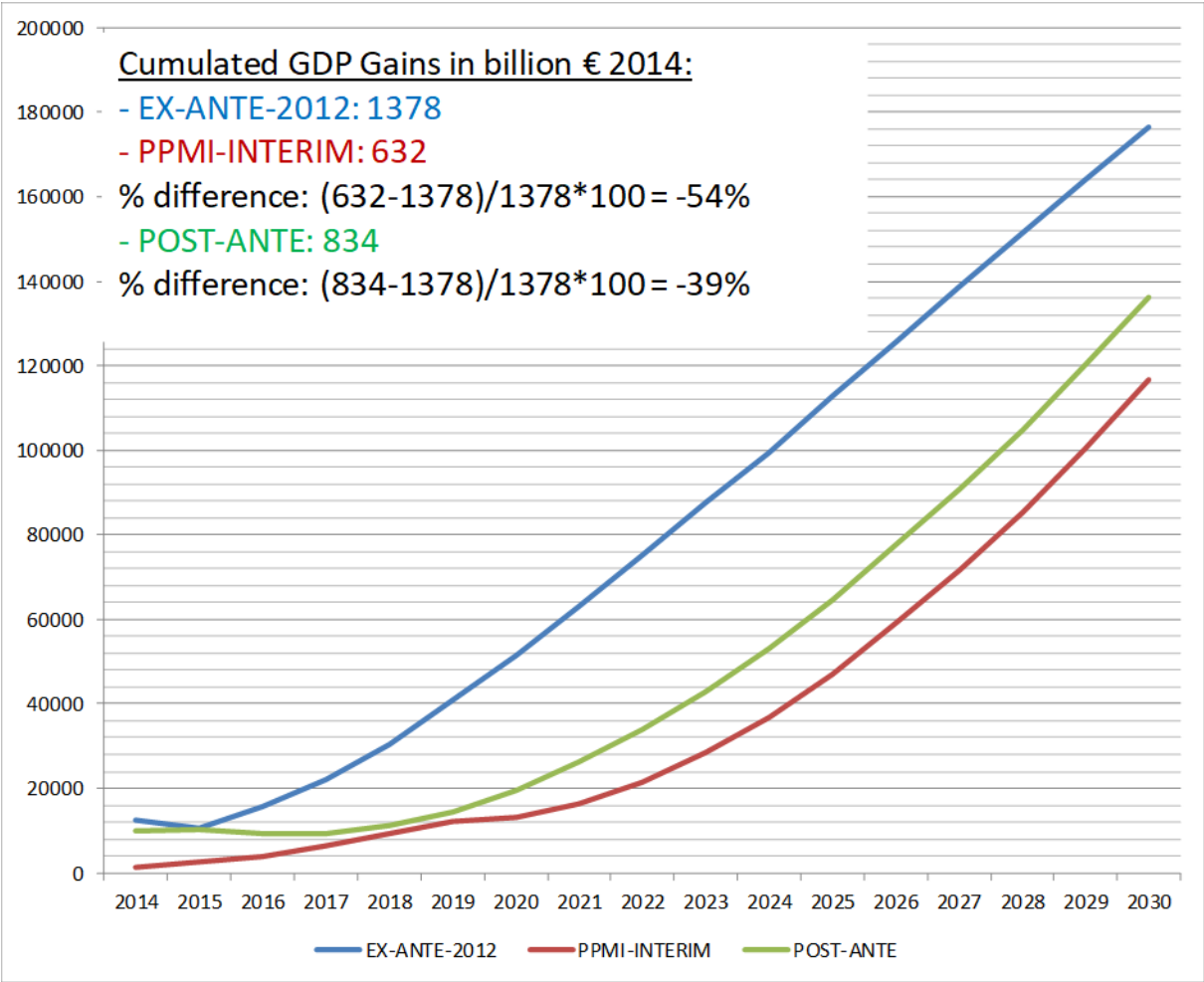


Source: Calculation based NEMESIS model data

Then, to enhance the comparison of the two assessments, it is necessary to simulate a new scenario, that we have called “*POST-ANTE*”, where exactly the same annual budget (*i.e.* annual EC contribution) as in the ex-ante assessment is introduced in NEMESIS.

Thus, we see in figure 6.7.3 that the difference in the accumulated EU GDP gains between the two assessments decreases from -54%, for “*PPMI-INTERIM*” compared to “*EX-ANTE-2012*”, to only -39% (when comparing this time with “*POST-ANTE*”). The difference in the budget spent over 2014-2020 period therefore explains 15% of the difference in the annual accumulated GDP gains between the two assessments.

Figure 6.7.3 – Comparison of GDP gains between the *ex-ante* and the *interim* assessments when correcting for the difference in the budget spent between 2014 and 2020 (million euros on left axis)



Source: NEMESIS model

6.7.3 Explaining the difference: The role played by the other methodological issues

A large part of the remaining difference of -39% for GDP gains comes, as we will see now, in the values retained for the crowding-in effect of the EC contribution (see table 6.7.1). In the *ex-ante* assessment, this crowding-in effect was equal to 0.86 euro (each euro of EC contribution leading to an additional R&D expenditure of 0.86). Its value was mainly based on the funding scheme that was supposed for

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the programme¹¹, and it was imputed exogenously in the model. In the present study, the crowding-in effect has two dimensions:

1. A direct crowding-in effect of 0.16 euro, based on the comparison of the total cost of the projects financed by H2020, from the beginning of 2014 up to August 2016, with the amount of the EC contribution during the same period.
2. An indirect crowding-in effect, calculated by the model, with an average value of 0.08. We finally obtain a total crowding-in factor of $0.16 + 0.08 = 0.24$ Euro.

Table 6.7.1 – Comparison of the assumptions used in the two assessments

	Ex-ante assessment (EC, 2012)	Current study ('H2020 forever')
FP funding 2014-2020 (in euro 2014)	2014: 10.7 billion 2015: 11.2 billion 2016: 11.6 billion 2017: 12.1 billion 2018: 12.6 billion 2019: 13.1 billion 2020: 13.6 billion Total: 84.9 billion	2014: 1.6 billion 2015: 3.1 billion 2016: 4.8 billion 2017: 7.8 billion 2018: 10.8 billion 2019: 13.7 billion 2020: 13.7 billion 2021: 9.2 billion 2022: 4.6 billion Total: 69.3 billion
FP funding 2021-2030 (in euro 2014)	+0.45 billion every year	+0.45 billion every year
Total FP funding 2014-2030 (in euro 2014)	246 billion	217 billion
Allocation of FP funding to EU MS	Based on Innovation performance (scoreboard)	Based on observed allocation (2014 to mid-2016)
Allocation of FP funding for basic and applied research	Basic: 40 % Applied: 60 %	Basic: 35 % Applied: 65 % (Based on observed allocation - 2014 to mid-2016)
Allocation of FP applied research funding to sectors within MS	Grandfathering principle	Grandfathering principle
FP funding average crowding-in (or leverage effect) on R&D effort of public and private research organisations	0.86	0.24
Total leverage (euro 2014) for the whole 2014-2030 period	211 billion (0.86*246)	51 billion (0.24*217)
Economic performance of R&D funding from EU	15 % better than national	15 % better than national

Source: Authors' calculations

¹¹And especially from the high leverage that was expected from the introduction of the InnovFin instrument.

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Let's apply the same total crowding-in effect in the current assessment as in the ex-ante study, using the same annual H2020 budget as in "POST-ANTE"; we can now estimate the impact of the difference in the total crowding-in effect on EU GDP gains.

Table 6.7.2 – Comparison of the *EX-ANTE-2012* and *PPMI-INTERIM* assessments for GDP and employment for the year 2030

	Average annual EU GDP gain (between 2014 and 2030, in millions euro 2014)	Average annual EU employment gains (between 2014 and 2030, in thousands)
EX-ANTE-2012	81 087	494
PPMI-INTERIM	37 199	278
Differences	-43 888 (-54 %)	-276 (-44 %)
Analysis of the difference		
- Budget	-11 869 (-15 %)	-80 (-16 %)
- Total crowding-in	-21 298 (-26 %)	-168 (-34 %)
- Other	-10 720 (-13 %)	+32 (+7 %)

Source: Authors' calculations from NEMESIS results

Table 6.7.2 finally shows the difference in EU GDP gains between the two assessments that can be attributed respectively (i) to the difference in the size of the H2020 budget, (ii) to the difference in the total crowding-in effect and (iii) to the influence of other factors. These other factors are:

1. The allocation of EC contribution between member states. In the *ex-ante* assessment, this allocation was based on the performance (i.e. on the scoreboard innovation ranking of the different EU countries) whereas for "PPMI-INTERIM", this national allocation is based on observed data (eCORDA, for a period covering the beginning of 2014 up to August 2016);
2. The split between basic and applied research. In the *ex-ante* assessment 40% of the funds are used for basic and 60% for applied research, whereas in the "PPMI-INTERIM" this split was based on observed data (from 2014 to mid-2016) and leads to 35% for basic and 65% for applied research.
3. The version of the NEMESIS model used. In the *ex-ante* assessment, the earlier version of the model, where innovation only comes from investments in public and private R&D, was used,

while “*PPMI-INTERIM*” uses the new version of the model where innovation also comes from investments in ICT and in intangible assets other than R&D (training and software).

For “*EX-ANTE-2012*”, the average annual GDP gains over the period 2014-2030 reach 81 billion euros (at 2014 prices), whereas these gains are limited to 37 billion euros for “*PPMI-INTERIM*”. This -54% difference for “*PPMI-INTERIM*” was due for -15% to the difference in the size of the budget, for -26% for the difference in the crowding-in effect and for -13% to the other factors.

Using the same calculations for employment, the table 6.7.2 shows that, for the period 2014-2030, the average annual employment gains are about 494 thousand for “*EX-ANTE-2012*”, against only 278 thousand for “*PPMI-INTERIM*”. This -44% difference for “*PPMI-INTERIM*” is due for -16% to the difference in the size of the budget, for -34% to the difference in the crowding-in effect, and for +7% to the other factors, that this time act positively in the comparison.

If we focus on the comparison of the results for the year 2030, we have a slightly different picture (see table 6.7.3):

- For GDP, the difference between “*EX-ANTE-2012*” and “*PPMI-INTERIM*” decreases from -54% to only -34%. Of these -34%, -11% come from the difference in budget, -28% from the difference in the crowding-in effect, and +5% from other factors that positively act in the comparison.
- For employment, the difference between “*EX-ANTE-2012*” and “*PPMI-INTERIM*” decreases from -44% previously to -35%. Of these -35%, -13% come from the difference in budget, -28% from the difference in the crowding-in effect and +7% from other factors that again act positively in the comparison.

Table 6.7.3 – Comparison of the *EX-ANTE-2012* and *PPMI-INTERIM* assessments for GDP and employment for the year 2030

	EU GDP gain (in 2030, in million euro 2014)	EU employment gains (in 2030, in thousands)
EX-ANTE-2012	176,392	914
PPMI-INTERIM	116,712	598
Differences	-55,640 (-34%)	-316 (-35%)
Analysis of the difference		
- Budget	-19,358 (-11%)	-123 (-13%)
- Total crowding-in	-49,134 (-28%)	-260 (-28%)
- Other	+8,812 (+5%)	+67 (+7%)

Source: Authors' calculations from NEMESIS results

Two main conclusions emerge from this comparison:

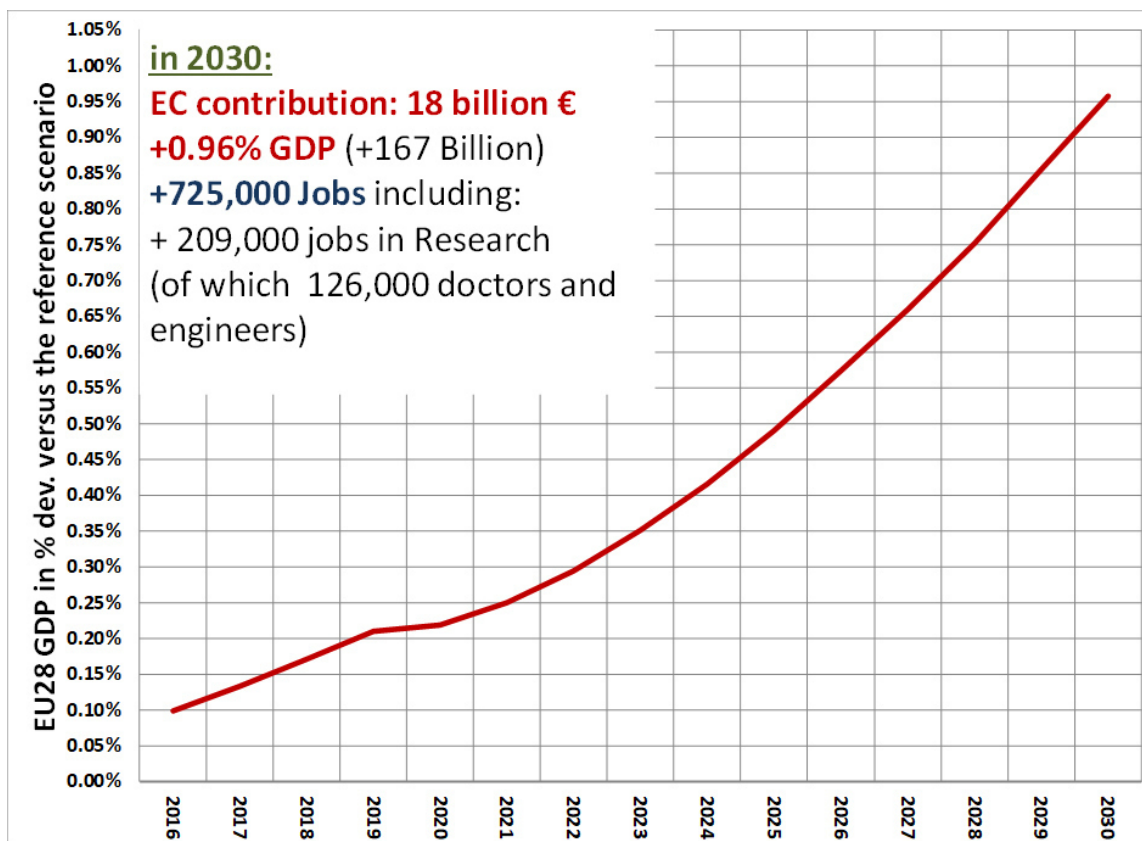
1. The main differences in the results, between the two assessments, comes from the different assumptions used for the crowding-in effect (0.86 in the *ex-ante* study and 0.24 now) and from the size of the total H2020 budget that was introduced in NEMESIS (246 billion Euros in the *ex-ante* study and 217 billion in the *interim* one).
2. Other factors only have a slight impact on the differences of results. Nevertheless it appears that the new version of the NEMESIS model minors slightly the GDP and employment gains in the short to medium term and, on the contrary, increases them in the longer term. This results from the complementarity between the three innovation inputs now present in the model, that slowdowns the arrival of innovations, but amplifies their impacts in the long term, for the better representation of innovation in service sectors in this new version of the model.

6.7.4 “H2020 forever” and ex-ante/interim comparison: the “Optimistic” case

For H2020, we finally investigated the macroeconomic impacts of continuing H2020 after 2020, but by this time retaining a value of +21% for the economic performance and of 0.34 for the direct crowding-in effect, like in the scenario “*Optimistic*” of section 6.5.1.

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Figure 6.7.4 – Results of a forever scenario under “*Optimistic*” assumptions at EU level (in % deviation w.r.t. reference scenario)



Source: NEMESIS model

For year 2030 (figure 6.7.4), the EU GDP gains reach about 0.96% (167 billion), against only 0.8% (140 billion) in the “*H2020 forever*” scenario (i.e. 20% higher). For employment, the gains in 2030 amount to about 725,000 against only 596,000 in “*H2020 Forever*” (i.e. 22% higher).

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Table 6.7.4 – Comparison with the *EX-ANTE-2012* using “*Optimistic*” assumptions for the period 2014-2030

	Average annual EU GDP gain (between 2014 and 2030, in million euro 2014)	Average annual EU employment gains (between 2014 and 2030, in thousands)
EX-ANTE-2012	81,087	494
FOREVER “OPTIMISTIC”	44,956	323
Differences	-36,131 (-45%)	-170 (-35%)

Analysis of the difference		
- Budget	-15,382 (-19%)	-104 (-21%)
- Total crowding-in	-14,344 (-18%)	-115 (-23%)
- Other	-6,405 (-8%)	+48 (+10%)

Source: Authors’ calculations from NEMESIS results

Let’s look at the comparison with the *ex-ante* assessment of H2020 again; we see in Table 6.7.4 that the higher values retained for the economic performance (+21% against +15% in “*H2020 forever*”) and for the direct crowding-in effect (0.34 against 0.16 in “*H2020 forever*”), reduce the gap in the average annual GDP and employment gains, between 2014 and 2030, that were measured in the *ex-ante* assessment and those that are now measured (“*FOREVER OPTIMISTIC*” in table6.7.4).

For EU GDP, the gains are 45% inferior to those in the *ex-ante* assessment, compared to 54% previously. This difference of -45% is explained for -19% by the difference in the size of the total H2020 budget (217 billion against 246 billion in “EX-ANTE-2012”), for -18% by the difference of total crowding-in (0.45 against 0.86) and for the remaining -8% by other factors. For EU employment, the gap in the annual average employment gains between the two evaluations is reduced from -44% previously to only -35%. This difference of -35% is explained for -21% by the difference in the size of the total H2020 budget, for -23% by the difference in the total crowding-in and for the +10% by other factors.

Table 6.7.5 – Comparison with the *EX-ANTE-2012* using “*Optimistic*” assumptions for the year 2030

	EU GDP gain (in 2030, in million euro 2014)	EU employment gains (in 2030, in thousands)
EX-ANTE-2012	176,392	914
FOREVER “OPTIMISTIC”	140,889	727
Differences	-35,503 (-20%)	-187 (-20%)
Analysis of the difference		
- Budget	-28,649 (-16%)	-168 (-18%)
- Total crowding-in	-29,034 (-16%)	-153 (-17%)
- Other	+22,179 (+13%)	+135 (+15%)

Source: Authors’ calculations from NEMESIS results

Finally, looking at year 2030 alone (table 6.7.5), there is little difference in the two results. This difference for EU GDP passes from -34% to -20%, -16% of the remaining difference being attributable to the budget size, -16% to difference in the crowding-in and +13% to other factors. For employment, the difference is reduced from -35% to -20% and explained for -18% by the budget size, -17% by the difference in the total crowding-in and +15% by other factors.

6.8 Summary of main findings and discussions

In October 2015 the DG RTD contracted a study to assess the EU Added Value (EAV) and socio-economic and environmental impacts of Horizon 2020. This analysis consisted in comparing the situation of the EU economy in the short (during the execution of the research programme), medium (2030) and long term (2050), using a reference scenario where, by assumption, the Framework Programme would have ceased in 2014, after the end of FP7. The analysis was based on the allocation of the H2020 budget between basic and applied research in the different Member States observed over the period 2014-2016.

Based on historical data, the total amount of the EC contribution for 2014-2016 was 14.2 billion constant (2014) euros, of a total of 69.3 billion euros retained in the study for the whole 2014-2020 period. By comparing the total amount of the EC contribution for 2014-2016, with the total cost

of the programmes, we could estimate the direct leverage effect of the EC contribution on the R&D effort of research organizations. The result was that each euro financed by the EC budget provoked an additional investment of 0.16 euro for the period 2014-2016 (direct crowding-in effect). The same direct crowding-in effect of the EC contribution was assumed for the period 2017 to 2020. For the whole H2020 programme, taking into account this direct crowding-in effect, there are 80 billion euros of R&D expenditure directly provoked by EC funding.

The rest of this section now recaps the main findings of the evaluation of this H2020 programme using the NEMESIS model. Then, it opens out the discussion on the methodology used, and the ways it could be improved in the future.

6.8.1 A summary of the socioeconomic and environmental impacts

The impact of the total H2020 budget From the calculations of the NEMESIS model, the socioeconomic impacts of the H2020 programme would reach their maximum in around 2030, and stay positive up to 2050. They can be summarized as follows:

1. H2020 funding could bring a GDP gain of 0.29% (50 billion in constant euros of 2014) by 2030. On average during the 2014-2030 period, the GDP gain represents about 27 billion euros per year;
2. Job creations will reach a maximum in 2019 with 276,000 new jobs including 150,000 jobs in research (92,000 doctors and engineers and 57,000 other research personal: Technicians and Administrative). In 2030, job creations will amount to 272,000, with only 8,000 in research. On average, for the period 2014-2030, the EC contribution will have increased the level of employment of 137,000, including 54,000 in research;
3. Over the period 2014-2030, each euro spent by the EC will have provoked a GDP increase of about 6.6 euros;
4. The internal rate of return of the EC contribution will reach 30% in 2030 and 32% in 2050;
5. Investments in research provoked by H2020 will increase labor productivity by 0.2% in 2030;
6. The impact of H2020 on EU external competitiveness will increase net exports by about 19 billion euros in 2030 (about 38% of GDP gains);

7. The final energy consumption by unit of GDP will decrease by 0.15%, and energy-related CO₂ emissions by 0.15%, in 2030.

The impact of the H2020 budget spent during the 2014-2016 period The impacts of the funds spent during the period 2014-2016 have also been assessed with the results:

1. On average between 2014 and 2030, H2020 funds for the period 2014-2016 will have increased the level of GDP by 5,7 billion euros per year;
2. The multiplier calculated for the total cost of the projects financed during this first period of the programme will be, in 2030, 6 euros GDP gain per euro of R&D invested in H2020 projects;
3. On average for 2014-2030, H2020 funds for 2014-2016 will have increased the level of employment each year by 29,000, compared to the level of employment in the reference scenario, including 10,100 jobs in research;
4. The internal rate of return for the funds for the 2014-2016 period will reach 27% in 2030, and 28% in 2050.

Sensitivity analysis on key NEMESIS model parameters The study has also underlined the great sensitivity of the results to the value of two key parameters:

1. The over-performance (EAV) of the R&D that is financed by the EC framework programmes compared to the performance of national research programmes, that we fixed at +15%;
2. The direct crowding-in effect that the EU R&D subsidies have on the research organizations that receive the funding, that we fixed at 0.16.

From the micro works that were performed in the study, on FP7 and first period of H2020 data, it appears that these two values are rather conservative, and in an “*Optimistic*” scenario, alternative values of respectively +0.21% and 0.34 were used. With these new assumptions the impact of the H2020 programme would provoke on average, during the period 2014-2030, 22% higher GDP gains, and 24% higher impact on employment. On the other hand, by retaining the value of 0.16 for the crowding-in effect, and considering that there is no EAV on the research that is financed at the EU level, compared to the national level, the GDP and employment impacts would be reduced by respectively -11% and -20%.

Comparison with the 2012 ex-ante assessment The impacts on GDP and employment measured in this *interim* assessment of H2020 programme were finally compared to those of the *ex-ante* assessment, that was achieved in 2012. This comparison was not direct, because in the *ex-ante* assessment of 2012, it was supposed that the programme will be prolonged after 2020 up to 2030, with an increase each year of 450 million constant euros. The only feasible comparison was therefore to simulate a scenario, called “*H2020 forever*”, where the programme was similarly continued after 2020, and also with an increase of 450 million euros each year after 2020.

The result from this comparison was that on average, for the period 2014-2030, the GDP and employment impacts of H2020 measured in the *interim* evaluation, are respectively -54% and -44% inferior than in the *ex-ante* evaluation of the programme. The differences between the two assessments result from:

1. The size of the H2020 budget: it was 12% lower for the *interim* evaluation than for the *ex-ante* assessment, reducing respectively the GDP and employment gains estimated with the model by -15% and -16% ;
2. The size of the crowding-in effect, that was fixed at 0.24 in the *interim* evaluation (0.16 for the direct leverage effect plus 0.08 for the indirect leverage), compared with 0.86 in the *ex-ante* study. This difference in the value of the crowding-in effect explains respectively -26% and -34% in the reduction of the GDP and employment gains that were estimated in the *interim* study;
3. The role of other factors, such as the sharing between basic and applied research, the temporal allocation of the programme, the version of the model used, ..., that explains -13% of the remaining difference between the two assessments for GDP, and +7% for employment.

6.8.2 Lessons for future evaluations of EC R&I programmes

Some “*lessons*” can finally be taken from this *interim* evaluation of the H2020 research programme, that could be useful for future assessments of EC R&I framework programmes. There are four main points:

- Firstly, it is important to take stock of past experience in order to fix relevant values for key parameters for the evaluation. They mainly concern the EAV of the EC R&I programmes, and their leverage effect on the R&D effort of the recipient research organizations:

- For the calculation of the EAV, the *ex-post* assessment of the FP7 (see PPMI, 2017, [272]), could provide crucial information on the relative performance of the EC research programmes, compared to national ones, in terms of research outcomes (patent applications and patent citations, the quality of scientific publications, new designs, new prototypes, new processes and products...) and economic performance (sale of innovative products, net exports in non-EU countries, ...). These impacts take time to develop, especially for economic impacts, and in the case of FP7, three years after the *ex-post* evaluation of the programme, the main economic impacts were still expected in the future. Nevertheless, the micro works that were performed based on FP7 data, allowed a better assessment of this EAV of the EC framework programmes. The +7% that was used in the *ex-ante* impact assessment of the FP7 programme, was therefore certainly under-estimated, and the +15% that was retained in the *ex-ante* and *interim* impact assessments of the H2020 programmes, is certainly more appropriate, even if the *ex-post* assessment of FP7 would suggest that +21% would be even more accurate.
- For the leverage effect of the programme, the change in the funding rules between FP7 and H2020, that was not anticipated at the time of the *ex-ante* evaluation of the H2020 programme, in 2012 (see again PPMI, 2017, [272]), has certainly resulted in an over-evaluation on this leverage effect for the H2020 programme. It was fixed at 0.86 in the *ex-ante* assessment, against only 0.24 in the *interim* evaluation. As we have seen, these 0.24 retained for the *interim* evaluation are probably a lower limit, if we consider the indirect cost of the programmes following the FP7 experience, and the value 0.42 could be more accurate (0.34 for the direct crowding-in, and 0.08 for the indirect one). Therefore, taking stock of past FP programmes data, and evaluation, allows for a more accurate appreciation of the value of this second crucial parameter, and also provides consistent lower and upper limits in order to mark out the limits of the potential impacts.
- Secondly, concerning the general methodology, two different approaches were used for the *ex-ante* and the *interim* assessments of H2020. For the *ex-ante* study (see European Commission, 2012, [115]), the assessment was undertaken in the “*continuation*” of the preceding FP7 programme, and with the assumption that H2020 will continue “forever” after 2020. This approach, that we call “*Continuation*”, is close to the true implementation of the framework programmes, that succeed one to another, but with the changing rules and general outlines of the successive

programmes, that have continuously evolved from pure research, to actions closer to the market and more oriented on societal challenges. It is for example again the case with the next Horizon Europe programme, and its “*Openness*” and “*Mission oriented*” policy approach, for more transparency in R&I partnerships that should target strategic priorities. This “*continuation*” approach therefore focuses the assessment on the improvement the new programme represents compared to its predecessor. This is also to evaluate the long-term impacts, from the “*forever*” assumption. In the case of the *interim* evaluation of H2020, on the contrary we assumed that H2020 was a “*one-off*” programme, without any predecessor, or successor after the end of the programme. This way of assessing the programme certainly eases the cost-benefit analysis: How many economic benefits will each euro spent in the programme provoke? But it does not allow to easily evaluate how much, and through which channels, the current programme improves the last one, or how the next one will improve the current one. It does not allow, either, to evaluate the long term impacts of the programme under scrutiny. The two approaches, the “*continuation*” and the “*discontinuation*”, are therefore complementary, and should both be considered in the assessments.

- Thirdly, concerning the “*financing*” of the programme, for the *ex-ante* and the *interim* evaluations of H2020, it was considered that this financing was coming “*out of nowhere*”. Proceeding in this way provides an evaluation of the programmes *per se*, without other considerations such as the possible arbitrages in the allocation of the overall EU budget between its main purposes (CAP, ESI funds and R&I FP), or the financing of the EU R&I programmes, *i.e.* the source of the funds. As we saw in chapter 4, concerning the next Horizon Europe programme, it was assumed on the contrary that the funding of the programme did not come from nowhere, and assumptions were made on the origin of the funds. This way of conducting the assessment certainly provides a different picture of the impact of the programme, and here again, the two approaches - the funds “*come*” / “*do not come*” out of nowhere - should certainly be considered.
- Fourthly, the results of the evaluation are extremely dependent on the economic tradition which the macro models used for the assessment belong to, and on the innovation mechanisms that the different models have. Future evaluations of EC R&I programmes could be more successful if, added to the first three points above, the different models could be harmonized, making the comparison between their results more accurate.

Chapter 7

Investigating the Impacts of the Innovation Union (I3U)

Chapter 7. Investigating the Impacts of the Innovation Union (I3U)

This last chapter presents an evaluation of the Europe 2020 Flagship Initiative Innovation Union (see European Commission, 2011, [70]) that was achieved in the context of the H2020 Research Programme I3U¹, Investigating the Impact of the Innovation Union, between March 2015 and September 2018.

After an introduction to the Innovation Union flagship initiative, its 34 commitments, and to the strategy adopted by the I3U project to assess their impact, we propose, using the I3U project results, to respond to two questions.

The first is: Where are we following the 2008 financial crisis? We answer this question in three complementary ways, starting with the characterization of the current state of the Innovation Union provided by the “*Conceptual model*” that was developed by the UNU-MERIT (Maastricht University) for the I3U project. We continue with the analysis of the progress made by the Innovation Union after the 2008 financial crisis, as measured by the European Innovation Scoreboard. We examine finally, using the NEMESIS model, how R&D investments by corporate and public sectors have impacted on the EU economy since 2008.

The second question is: What are the perspectives under current trends? This will examine the impacts for the EU economy in the future, of the progress observed in the implementation of the Innovation Union under “*current trends*”. We analyze the socioeconomic impacts of the commitments implemented in the NEMESIS model individually, by groups, and as a whole. We also analyze the results obtained for a “*more ambitious scenario*”, where individual commitments implementation is reinforced compared to “*current trends*”, by assuming improvement in existing policies, or the implementation of additional policies.

Of course, there is no room here to go into all the details of I3U project results. Therefore, we will propose a synthesis and examples of the main project results, and the interested reader could visit the I3U website for more information.

¹See: <http://www.i3u-innovationunion.eu/>

7.1 The Innovation Union Flagship Initiative and the I3U H2020 Research Project

7.1.1 Europe 2020 and the Innovation Union Flagship initiative

The Innovation Union is one of seven Europe 2020 strategy flagship initiatives, that each propose a set of specific proposals and instruments that should be implemented before 2020 to achieve the aims of Europe 2020, with five headline target²:

1. Raise employment among 20-64 year olds from 69% to at least 75%;
2. Achieve 3% GDP invested in R&D, improve the conditions for R&D investment in the private sector, and develop a new indicator for innovation;
3. Reduce greenhouse gas emissions by at least 20% compared to 1990 levels, increase renewable energies to 20%, and achieve a 20% increase in energy efficiency.
4. Reduce the share of early school leavers to 10% from the current 15% and increase the share of population aged 30-34 having completed tertiary education from 31% to at least 40%;
5. Reduce the number of Europeans living below the national poverty lines by lifting at least 20 million people out of poverty and social exclusion.

The seven flagships initiatives are:

1. **Innovation Union**, to improve the conditions and access to finance for research and innovation, so as to strengthen the innovation chain and boost investment throughout the Union;
2. **Youth on the move**, to enhance the performance of the education system and reinforce the international attractiveness of Europe's higher education;
3. **A digital agenda for Europe**, to speed up the roll-out of high-speed internet and reap the benefits of a digital single market for households and firms;
4. **Resource efficient Europe**, to help decouple economic growth from the use of resources, by de-carbonizing the economy, increasing the use of renewable resources, modernizing the transport sector and promoting energy efficiency;

²See Europe 2020 Factsheet: <https://all-digital.org/wp-content/uploads/2015/11/Europe-2020-factsheet-TE-2015.pdf>

5. **An industrial policy for globalization**, to improve the business environment, especially the SMEs, and to support the development of a strong and sustainable industrial base, able to compete globally;
6. **An agenda for new skills and jobs**, to modernize the labor markets by facilitating labor mobility and the development of skills throughout the life cycle, with a view to increasing labor participation and better matching of labor supply and demand;
7. **European platform against poverty**, to ensure social and territorial cohesion so the benefits of growth and jobs are widely shared, and those experiencing poverty and social exclusion can live in dignity and take an active part in society.

Compared to the preceding Lisbon strategy (2000-2010), with the financial crisis and the strong economic contraction and rise in unemployment rates, it became evident, that the Europe 2020 strategy, pre-existing social and environmental concerns should aimed at fostering growth, notably by taking advantage of the new economic realities. Therefore the strategy stresses a key role for development of using and investing in communication and information technologies in 5 of the 7 flagship initiatives: Youth on the move, A digital agenda for Europe, An agenda for new skills and jobs, European platform against poverty and Innovation Union. The Innovation Union has a key role to play in addressing the pre-existing long-term challenges of the Union, that became again more pressing after the financial crisis: globalization, ageing populations and the pressure on natural resources. Research and innovation policies were placed at the core of this Europe 2020 strategy, and considered as central to face all these structural changes, and to tackle the major societal challenges

Europe 2020 was introduced by the European Commission on 3 March 2010, and in 2014 the European Commission conducted a public consultation on its mid-term review and published the results in March 2015³. The European Commission was obliged to recognize that progress was limited. We see from the last update in September 2018 of the Europe 2020 Headline indicators published by EUROSTAT⁴, that compared to 2008, progress is nevertheless on the way:

- The employment rate in the 20-64 age group slightly increased in 2016 to 71.1%, against 70.3% in 2008, but is still far from the 75% target;

³See: <http://www.europarl.europa.eu/legislative-train/theme-new-boost-for-jobs-growth-and-investment/file-mid-term-review-europe-2020-strategy>

⁴See: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Europe_2020_headline_indicators,_EU-28,_2008_and_2012%E2%80%932016.PNG

- Greenhouse gas emissions have reduce by 22.1% in 2015 against 9.4% in 2008, below the target of -20%. The same year the share of renewable energies in gross final energy consumption was 16.7%, against 11% in 2008, still below the 20% target;
- Early leavers from education and training was reduced to 10.7% in 2016, against 14.7% in 2008, with a target at 10%; the tertiary educational attainment in % of the population aged 30-34 reached 39.1% in 2016, against 31.1% in 2008, and a target superior to 40%;
- The R&D intensity of the EU-28 reached 2.02% in 2015, against 1.84% in 2008, still very far from the 3% target.

This contrast between the important role attributed to the EU R&I policy in Europe 2020 strategy, and the very limited increase in R&D intensity, underlined the necessity for an in-depth assessment of the Innovation Union flagship initiative, that was achieved in the context of the I3U research project.

7.1.2 The Innovation Union 34 Commitments and their Assessment in I3U

The objective of the I3U project consisted in “(...) *gathering evidence on the impact of the EU innovation policy on growth and jobs in the EU and the Member States*”. A related aim was to analyze how this R&I strategy could be improved in the future.

The task was not easy, as the Innovation Union includes 34 different commitments covering many different topics organized in thirteen clusters of aims:

1. **Promoting excellence in education and skills development**, with **Commitment 1** for Member states to develop strategies to *train enough researchers to meet their national R&D targets and to promote attractive employment conditions* in public research institutions, **Commitment 2** to support *an independent multi-dimensional inter-temporal ranking system to benchmark university performance*, **Commitment 3** to support *business-academia Knowledge Alliances* and develop *new curricula addressing innovation skills gaps*, and **Commitment 4** for the *development and promotion of e-skills for innovation and competitiveness*;
2. **Delivering the European Research Area**, with **Commitment 4** with the introduction by the European Commission of a *European Research Area framework and supporting measures to remove obstacles to mobility and cross-boarder cooperation*, and **Commitment 5** targeting for 2015 the completion or launch by Member States together with the Commission of 60% of

the *priority European research infrastructures* identified by the European Strategy Forum for Research Infrastructures (ESFRI⁵);

3. **Focusing EU funding instruments on Innovation Union Priorities**, with **Commitment 6** focusing on the *redirection of future EU research and innovation programmes on Europe 2020 objectives* and particularly the Innovation Union, with *future programmes more oriented on societal challenges*, streamlining funding instruments and radically simplifying access through a better balance between a control-based and a trust-based system, **Commitment 7** to ensure *simple access and stronger involvement of SMEs in future EC R&I programmes*, and **Commitment 8** that aims to *strengthen the scientific base for policy making through its Joint Research Center* and the *creation of an European Forum on Forward Looking Activities*;
4. **Promoting the European Institute of Innovation and Technology (EIT) as a model of innovation governance in Europe**, with **Commitment 9** that says *by mid-2011 the EIT should set out a Strategic Innovation Agenda* to expand its activities, including the creation of new KICs⁶;
5. **Enhancing access to finance for innovative companies**, with **Commitment 10** that says *Commission proposals will put in place financial instruments to attract a major increase in private finance by 2014*, that will ensure a high leverage effect, efficient management and simple access for business, **Commitment 11** that says that by 2012, at the initiative of the Commission, *Venture capital funds established in any Member State can function and invest freely in the EU*, with, notably, the elimination of any tax treatment unfavorable to cross-border activities, **Commitment 12** to *strengthen cross-border matching of innovative firms with suitable investors*, and **Commitment 13** engages the Commission to conduct a *mid-term review of State aid research and development and the innovation framework*;
6. **Creating a single innovation market**, with **Commitment 14** to take the necessary steps to adopt the proposals on *the EU patent with the objective that the first EU patents are delivered by 2014*, **Commitment 15** *introducing from 2011 for Member States, a screening of the regulatory framework in key areas, starting with those linked to eco-innovation and to European Innovation*

⁵See: https://ec.europa.eu/info/research-and-innovation/strategy/european-research-infrastructures_en

⁶These are partnerships that bring together businesses, research centers and Universities, each focusing on a different societal challenge, see: <https://eit.europa.eu/activities/innovation-communities>

Partnerships, Commitment 16 covering the ICT sector in order to speed up and modernize standard-setting to enable interoperability and foster innovation in fast-moving global markets, Commitment 17 promoting the development by Member States and regions of dedicated budgets for pre-commercial procurements of innovative products and services, and Commitment 18 with the introduction in 2011 by the Commission of a eco-innovation action plan;

7. **Promoting openness and capitalizing on Europe's creative potential**, with **Commitment 19** set up in 2011 by the Commission of a *European Design Leadership Board*, and of a *European Creative Industries Alliance*, **Commitment 20** to promote *open access to the results of publicly funded research*, **Commitment 21** to *facilitate effective collaborative research and knowledge transfer*, **Commitment 22** to *develop a European knowledge market for patents and licensing*, and **Commitment 23** to *examine the role of Competition Policy in safeguarding against the use of intellectual property rights and anti-competition purposes*;
8. **Spreading the benefits of innovation across the Union**, with **Commitment 24** *improving the use of existing Structural Funds for R&I* and **Commitment 25** *increasing the share of Structural Funds for R&I after 2013*;
9. **Increasing social benefits**, with **Commitment 26** and the launch by the Commission of a *European Social Innovation pilot*, **Commitment 27** supporting a *substantial research programme on public sector and social innovation*, and **Commitment 28** organizing the *consultation by the Commission of the social partners* to examine how the knowledge economy can be spread to all occupational levels and all sectors;
10. **European Innovation Partnerships**, with **Commitment 29** that invites the Council, Parliament, Member States, Industry and the other Stakeholders to *support innovation partnerships* and as a first step prepare the launch of a pilot partnership in 2011;
11. Leveraging out policies externally, with **Commitment 30** to attract a sufficient number of highly skilled third country nationals to stay in Europe, **Commitment 31** to foster cooperation with third countries, and **Commitment 32** for the roll-out of the global research infrastructures in collaboration with third countries;
12. **Reforming research and innovation systems**, with **Commitment 33** inviting Member States to carry out self assessments and identify key challenges and critical reforms as part of

their National Reform Programmes;

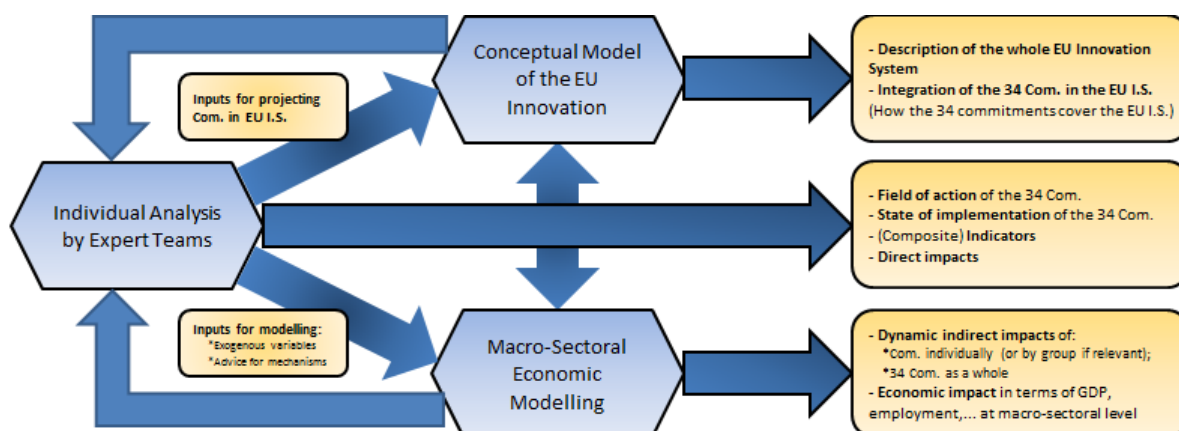
13. **Measuring progress**, with **Commitment 34** by which the Commission proposes to launch the necessary work for the development of a new indicator measuring the share of fast-growing innovative companies in the economy, and improve the Research and Innovation Union scoreboard.

Besides this diversity of objectives pursued by the Innovation Union, another difficulty for the I3U project is that the commitments, and groups of commitments, overlap and complement each other. Therefore, in the project, the general methodology that was adopted for the analysis of the 34 commitments and their interactions has been divided in three groups of actions (see figure 7.1.1):

1. **Individual Analysis by Expert Teams** of the commitments, using appropriate methodologies for each commitment;
2. The elaboration of a **Conceptual model of the EU Innovation** system, depicting the EU innovation system and the projection of the commitments' actions in that system, leading to an assessment of the commitments in that system;
3. **Macro-Sectorial Economic Modeling** with NEMESIS, to take into account the overall interactions with the eco-system and determine the resulting impact on economic variables.

The first group of actions, **Individual Analysis by Expert Teams** was implemented by seven different research teams that made a *direct assessment* of the commitments related to their field of

Figure 7.1.1 – Method for the impact assessment of the 34 commitments



Source: I3U Proposal-Part B

expertise, and addressed the following issues:

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- Identification of the mechanisms of action (rationale) of the different commitments;
- Assess the degree of completion (implementation) of the commitments, at Member State and/or EU level;
- Provide a direct impact assessment of the commitments by econometric or other suitable methods;
- Provide inputs for modeling:
 - For projecting commitments in the *Conceptual Model of the EU Innovation* system;
 - For the needs of *Macro-Sectorial Economic Modeling Using NEMESIS*.

For that purpose, the commitments were regrouped into eight work-packages (See table 7.1.1), following the key challenges listed above identified by the European Commission, with the aim of combining specific areas of expertise. The work-packages were themselves regrouped in three main clusters of actions:

1. Strengthening the knowledge base and reducing fragmentation;
2. Getting good ideas to the market;
3. Governance of innovation.

The teams in charge of these work-package and the commitments analysis were:

1. The Centre for Technology, Innovation and Culture (TIK) from the University of Oslo, with Fulvio Castellacci and Magnus Gulbrandsen;
2. The World Economy Research Institute (WERI) from the Warsaw School of Economics, with Marzenna Anna Weresa, Arkadiusz Michal Kowalski, Małgorzata Lewandowska, Marta Mackiewicz and Tomasz Napiórkowski;
3. The Institute of Economics, Zagreb (EIZ), with Sonja Radas, Andrea Mervar, Nevenka Čučković, Edo Rajh, Ivan Damir Anić, Bruno Škrinjarić and Valentina Vučković;
4. The International Centre for Innovation, Technology and Education Studies (iCite) of the Solvay Brussels School of Economics and Management at Université Libre de Bruxelles (ULB), with Michele Cincera, Virginie Maghe, Palina Shauchuk and Anabela Santos;

Table 7.1.1 – List of Issues and Work-Packages

WP	WP Leaders	Commitments/Issues	Leader partners	Clusters of WP
WP1	TIK	1 Member state strategies for researchers training and employment conditions	TIK	C1 Strengthening the knowledge base and reducing fragmentation
		2 "Personalised" university ranking	TIK	
		3 "Knowledge Alliances and Skills for Innovation"	TIK	
WP2	WERI	4 Propose an integrated framework for e-skills	TIK	
		5 European Research Area Communication	TIK	
		6 Construct the priority European Research Infrastructures	WERI	
		7 EU Research and Innovation Programmes	WERI	
		8 SMEs in Research and Innovation Programmes	EIZ	
		9 Strength science base for policy making through JRC; Forum on FLA	WERI	
WP3	ULB	10 Set out EIT strategic agenda	WERI	
		11 Put in place EU-level financial instruments to attract private finance	ULB	
		12 Access to Finance - Venture Capital	ULB	
		13 Access to Finance - Matching	ULB	
WP4	ZEW	14 Review State Aid Framework for R&D&I	ULB	
		15 Deliver the EU Patent	ZEW	
		16 Screen the regulatory framework in key areas	ZEW	
		17 Standardisation Strategy for Europe	ZEW	
WP5	ZEW	18 Public Procurement - Commission Support	WIIW	
		19 Eco-Innovation	WIIW	
		20 Creative Industries	ULB	
		21 European Design Leadership Board	ULB	
		22 Open Access to Research Results / Research Information Services	EIZ	
WP6	WIIW	23 Facilitating Effective Collaborative Research and Knowledge Transfer	EIZ	
		24/25 Develop a European knowledge market for patents and licensing	ZEW	
		26 Safeguard against the use of IPRs for anti-competitive purposes	ZEW	
		27 Maximising Social and Territorial Cohesion	WIIW	
WP7	WERI	28 European Social Innovation Pilot	WIIW	
		29 Public Sector Innovation Scoreboard	WERI	
		30 Research Programme on Public Sector and Social Innovation	WERI	
		31 Consult social partners on interaction between the knowledge economy and the labour market	WIIW	
WP8	ISINNOVA	32 European Innovation Partnerships	WIIW	
		33 Retaining and Attracting International Talent	TIK	
		34 Scientific Cooperation with Third Countries	EIZ	
WP9	MERIT	35 Roll-out global research infrastructures	WERI	
		36 Member States R&I Systems	ISINNOVA	
WP10	SEURECO	37 Develop an innovation headline indicator	ISINNOVA	
		38 Innovation Union Scoreboard	ISINNOVA	
		39 Conceptual Innovation System Model	MERIT	
		40 Scientific coordination	ULB	
		41 Sum up the effects to take into account	MERIT	
		42 Implementation in Macro-sectoral model	SEURECO	
WP11	ISINNOVA	43 Definition of a reference scenario	SEURECO	
		44 Analytical tests	SEURECO	
		45 Simulations by group of commitments	SEURECO	
		46 Simulations of commitments as a whole	SEURECO	
WP11	ISINNOVA	47 Administrative Management	ISINNOVA	
		48 Stakeholder Involvement	ISINNOVA	
		49 Conferences	ISINNOVA	
		50 Dissemination	MERIT	

Source: I3U Proposal-Part B

5. The Centre for European Economic Research (ZEW) in Mannheim, with Georg Licht, Bettina Peters, Christian Rammer, Paula Schliessler and Christian Koehler

6. The Vienna Institute for International Economic Studies (WIIW), with Michael Landesmann, Robert Stehrer, Johannes Pöschl, Sandra Leitner, Veronika Janýrová, Sandor Richter, Hermine Weinberger-Vidovic, Mahdi Ghodsi, Isilda Mara and Roman Römisch;
7. ISINNOVA - the Institute of Studies for the Integration of Systems (www.isinnova.org) - in Italy, with Andrea RICCI, Carlo Sessa and Loredana Marmora.

The team in charge of the second group of actions, **Conceptual model of the EU Innovation**, was the UNU-MERIT (Maastricht University), with Pierre Mohnen and Bart Verspagen, that also shared the scientific coordination of the I3U project. The team that developed the conceptual model had to work in close collaboration with the commitments' expert teams, in order to be able to project the action of the commitments in the model, and ensure the overall consistency of the individual analysis of the commitments when integrating them in a general framework.

Finally the team in charge of the third group of actions, the **Macro-Sectorial Economic Modeling**, was SEURECO (Société EUROpéenne d'ECONomie, France), that develops the NEMESIS model. In the same way, the team had to work in strong relationship with the different expert teams, to be able to implement the different commitments in the model, and calculate the impacts they have on economy at large.

Of course, after analysis of the individual commitments, it was soon evident that on the 40 commitments and sub-commitments⁷ that constitute the Innovation Union, not all could be implemented in NEMESIS, for two main reasons:

1. There are fourteen commitments, listed in table 7.1.2, that turned out to be “*simple statements*”, without quantifiable objectives that could be assessed using the NEMESIS model. This mainly concerned commitments related to the monitoring of Innovation Union, such as commitment C27.1 – “Public Sector Innovation Scoreboard” or related to planning activities such as commitments C9 – “Set out EIT strategic agenda” or C18 – “Eco-Innovation action plan”.
2. There is a second group of 11 commitments that were not included in NEMESIS, but that were classified by the commitments' expert teams as “*candidates*” for a future integration in the model. Their analysis confirmed they have an effect on innovation and on the economy at large, that could be simulated with NEMESIS, but they could not be introduced in the model at this stage,

⁷Commitments C1, C4, C19 and C27 include two sub-commitments, and the commitment C4 includes 3.

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Table 7.1.2 – List of commitments considered as “Simple statements”

Commitment	WP	Team	Explanation
2.1 University ranking	1	TIK	The ranking will present material for policy makers but will not have a direct impact on innovation.
4.3 Creation on pan-European pension funds for researchers	2	TIK	Lack of data, funding principle and responsible actors difficult to identify, legal obstacle in MS
8 Forward looking activities	2	WERI	Not quantifiable
9 Set out EIT strategic agenda	2	WERI	Not quantifiable
15 Screening of regulatory framework	4	ZEW	Not quantifiable
18 Eco-innovation action plan	4	WIIW	Not quantifiable
23 Safeguard rules for IP	4	ZEW	Need for data and empirical evidence of its effects
26 European social innovation pilot	6	WIIW	Many heterogeneous programmes initiated. No clear evidence of their effects
27 Public sector innovation scoreboard	6	WERI	Useful statistics for policy makers, but no direct impact on innovation
28 Consultation of social partners	6	WIIW	Policy in inception, will be only introduced in particular sectors
29 European innovation partnership	7	WIIW	Possible new sources of spillovers, finance and actions to market. Lack of data (no systematic evidence on EIPs actual performance and effects)
32 Roll-out global research infrastructures	7	WERI	Lack of data, lends itself better to a qualitative approach
33 Member States self-assessments R&I systems	8	ISINNOVA	Qualitative
34.1 New indicators and monitoring	8	ISINNOVA	Useful statistics for policy makers, but no direct impact on innovation

Source: Pierre Le Mouél, Baptiste Boitier and Paul Zagamé, 2019, [207].

either because the necessary data were missing, or because the econometric parameters needed to quantify their impacts were too uncertain. Others, as commitment 22 - “European market for patent and licensing”, were not yet implemented. All these are listed in the Table 2 that also provides explanations on the precise reasons for which the individual commitments were not implemented in NEMESIS.

There were finally 13 commitments left, listed in the table 7.1.4, that were implemented in the NEME-

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Table 7.1.3 – List of commitments considered as “Candidates”

Commitment	WP	Team	Explanation
1.1 Researcher’s training	1	TIK	Data exist, but too scarce to achieve robust estimations of the impacts
1.2 Employment conditions	1	TIK	Data exist, but too scarce to achieve robust estimations of the impacts
4.1 ERA – International collaboration	2	TII	Data exist, but too scarce to achieve robust estimations of the impacts
5 EU research and innovation infrastructures	2	WERI	Some data are available on the allocation of funds in FP7 and H2020, but data from national and private sources for research infrastructure are limited. Geographical distribution of EU funds can be investigated. An analysis, infrastructure per infrastructure, looks more appropriate to assess the impacts on scientific productivity and innovation.
7 SMEs in research and innovation programmes	2	EIZ	Data exist, but too scarce to achieve robust estimations of the impacts
16 Standardisation	4	ZEW	No data
17 Innovative Public Procurements	4	ZEW	No data except for Germany. Commitment implementation only beginning
20 Open access to research results	5	EIZ	Source of spillover, diffusion of knowledge, but difficult to quantify and to measure its impacts
21 Collaborative research and knowledge transfer	4	EIZ	Source of knowledge spillovers, but its impact and direction can hardly be quantified given present data.
22 European market for patent and licensing	6	ZEW	No policy change has yet been implemented
31 Scientific cooperation with third countries	7	EIZ	Source of spillovers (international) and knowledge capital, but data deficiency for inclusion in NEMESIS

Source: Pierre Le Mouël, Baptiste Boitier and Paul Zagamé, 2019, [207].

SIS model⁸. These commitments were introduced in NEMESIS individually, by groups and “as whole” to evaluate the overall impact of the Innovation Union. Four groups of commitments were considered:

1. Group 1 - “*Human capital*” included four commitments that all promote the development of

⁸Note that the commitment C14, “Unitary patent”, was finally not implemented in the NEMESIS model, as the results of the direct impact assessment of the commitment achieved by ZEW, that are available in the I3U project deliverables D4.2 - “State of implementation and direct impact assessment (WP4), Creating a single innovation market”, and D4.3 -, “Integration in the eco-system (WP4)”, have showed that changes in patenting costs would be too limited (about a few million Euros per year) to have significant impacts at the macro level.

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Table 7.1.4 – List of the IU commitments implemented in the NEMESIS model

WP Nb: (Team)	Commitment Nb:	Commitment category	
1 (TIK)	2.2	Knowledge alliances for skill gaps	Group 1
1 (TIK)	3	Propose an integrated framework for e-skill	Group 1
2 (TIK)	4.2	ERA - research mobility	Group 1
2 (WERI)	6	EU research and innovation programmes	Group 3
3 (ULB)	10	Put in place EU financial instruments to attract private finance	Group 2
3 (ULB)	11	Access to finance- Venture capital	Group 2
3 (ULB)	12	Access to finance - Matching	Group 2
3 (ULB)	13	Review State aid framework for R&D and innovation	Group 2
4 (ZEW)	14	European patent	Group 4
5 (ULB)	19.1	Creative industries	Group 4
5 (ULB)	19.2	EU design leadership board	Group 4
6 (WIIW)	24/25	Improve/increase the use of Structural Funds for R&I	Group 3
7 (TIK)	30	Foreign talents	Group 1

human capital and skills that could for example impact on productivity of research or increase knowledge spillovers. These were three commitments from WP1:

- C2.2 - “*Knowledge alliances for skill gaps*”;
- C3 - “*Propose an integrated framework for e-skill*”;
- C4.2 - “*ERA research mobility*”;

and one commitment from WP7:

- C30 - “*Foreign talents*”.

2. Group 2 - “*Finance*”, regrouped commitments aiming to facilitate the financing of firms’ innovation, and notably the access to finance for SMEs. It included the four commitments from WP3:

- C10 - “Put in place EU financial instruments to attract private finance”;
 - C11 - “Access to finance – Venture capital”;
 - C12 - “Access to finance – Matching”;
 - C13 - “Review State aid framework for R&D and innovation”.
3. Group 3 - “European funds” included three commitments focusing on the impact of EC funds, one from WP2:
- C6 - “EU research and innovation programmes”;
- and two from WP 6:
- C24/25 - “Improve/Increase the use of ESI funds for R&I”.
4. Group 4 - “Action to market”, finally regrouped commitments aiming at fostering market conditions for innovation. These were two commitments from WP 5:
- C19.1 - “Creative industries”;
 - C19.2 - “EU design leadership board”.

We see that though this list of 13 commitments analyzed with the model was limited, it nevertheless covered, compared to the “candidates” commitments (Table 7.1.3), many of the commitments for which quantitative impact could be expected *a priori*. And there are also the commitments for which the most important quantitative impacts could be expected, as those of Group 2 “Finance”, Group 3 “EU funds” and Group 1 “Human capital”.

This should have been also the case for commitment 5, “EU research and innovation infrastructure”, but unfortunately, it could not be integrated, *per se*, in the NEMESIS model. Nevertheless, though its individual impact was not assessed, as Research Infrastructures were also a part of the EU R&I Framework Programmes, some of its effects were included in the impacts assessment of commitment C6 – “EU research and innovation programmes”. Similarly, in C7 - “SMEs in research and innovation programmes”, overlapped with both C6 - “EU framework programmes” and C10 - “Put in place EU financial instruments to attract private finance”.

Finally, the commitments that were implemented in the model cover most of the 13 objectives pursued by the IU. We can therefore expect that, if not exhaustive, the list of commitments that were analyzed with NEMESIS, provides a relatively good picture of the socioeconomic impacts that the achievement of the IU could induce in the future.

7.2 Where are we following the 2008 financial crisis?

7.2.1 What we can learn from Conceptual Model of the European Innovation System⁹

The Conceptual Model of the Innovation system, developed by the UNU-MERIT in the context of the I3U project, was a unique attempt to apply the innovation systems theory to the quantitative analysis of the Innovation Union. The innovation systems theory is not often present in the quantitative evaluation of innovation policies; it is usually performed together with quantitative policy scenario simulations, like for NEMESIS, or with econometric works on the additionality and direct impacts of policies, like those made in I3U by the Innovation Union Commitments expert teams. The goal of this Conceptual Model was therefore to provide information to these two categories of quantitative works, on the nature and extent of innovation in EU Member States, with the idea that “(...) *it is not only important how much innovation is generated in a country, or region, but also how this innovation is generated, and what kind of innovation it is*” (Verspagen et al., 2017a, [328], page 3).

As the innovation systems theory is more often qualitative in nature, and applied to aspects of the innovation that are difficult to measure, the strategy was therefore to formalize this theory “*in a way that is compatible with quantitative analysis*”. For this, the innovation system theory (Freeman, 1987; Lundvall, 1992; Nelson, 1993) was combined with the idea of “*taxonomizing behavioral heterogeneity in the innovation process*”. This idea, following Pavitt (1984) and successfully applied by Srholec and Verspagen (2012, [303]) in the case of EU firms, is to reduce the large heterogeneity of firms prevailing at the micro level, to clusters that are “*manageable for analytical purposes*”. For the needs of the I3U project, the originality was also to “(...) *apply it to a wider range of actors than just firms, e.g. to universities, policymakers, banks and other financial institutions, research institutes, and consumers*”.

This Conceptual Model was based on three layers of analysis:

1. In Verspagen *et al.* (2017a, [328]), the analysis focused, using data on European Union Member States, on how the approach could produce taxonomies of behavioral patterns for these six actor categories in the innovation system. “*By combining the typical behavioral patterns found most often in the system, the nature of the system in the particular member states was characterized*”

⁹This section builds on the works Verspagen *et al.* (2017a, [328], and 2017b, [329]) on the I3U project, I3U deliverable D9.4 ([169]), and on the I3U policy brief of September 2018 ([168]) “*The State of the Innovation and the working of the European Innovation Systems*”.

*in terms of the way in which typical interactions take place in the system, and how much and what kind of innovation the system will tend to produce” (Verspagen et al., *ibid*, page).*

2. In Verspagen *et al.* (2017b, [329]), the analysis of public policy that was absent from the previous analysis was introduced as a separate category. Potential policy instruments were first classified in the field of Science (STI), Technology and Innovation (e.g., Vedung, [323], 1998; Bemelmans-Videc, [27], 2003) and then the ERAWATCH¹⁰ country reports were used for describing the actual policies implemented in the EU Member States. Then a principal components analysis was used to characterize the innovation policy system of the different countries.
3. Then, by also gathering information from the commitments’ expert team on their state of implementation in the different Member States, it was possible to project the action of the commitments in this Conceptual Model of the Innovation Union System (I3U deliverable D9.4, [169]).

We now recap their main findings.

7.2.1.1 Taxonomy of Member States Innovation Patterns

The analysis of the behavioral roles of the six classes of actors show that the combination of patterns plays a key role for characterizing the innovation behavior and the nature of innovation in different countries:

1. A first combination of behavioral patterns defines an innovation system characterized as *science-driven*. The higher education system is strongly research-driven and performs at high level (excellence). Research institutes also perform well, and provide links to firms. In the corporate sector, there are science-based firms, that perform a lot of R&D and have strong links with both universities and research institutes. Government plays a strong role in that system by organizing the system, with policies fostering public-private partnerships. The system produces radical innovations, and risk is high. This is the system that characterizes the best innovation systems in the US (Nelson, 1993, [248]) and *“It is also the archetype of system that is seen by many (European) policymakers as the most ideal type, corresponding closely to what is seen as the ‘pure’ type of innovation”* (Verspagen et al., 2017a, [328], page 33).

¹⁰The ERAWATCH platform has been recently phased out and replaced by the RIO-PSF (Research and Innovation Observatory - Horizon 2020 Policy Support Facility) website providing key information in the field of European and national R&I policies.

2. Then is the *absorption-oriented* system, where the corporate sector has strong “*externally-sourcing innovators*”. These are firms that innovate by investing in licensed technologies, innovative machinery and equipment, but do not develop their own technologies much. The role of university is mainly to help absorb external knowledge present in foreign technologies, and to adapt them. The university sector also plays a key role by providing the skills that are necessary for workers to absorb external knowledge. The research institute sector is market-oriented, and the role of the government in that system is “more generic and facilitating, aimed, for example, at a high overall level of universities rather than excellence *per se*” (Verspagen *et al.*, *ibid*, page 34). Based on external knowledge, the system is less risky, and the finance system does not need to be very risk-taking.
3. The next system is the *demand-driven* system, inspired by the research institutes sector. It is found in the countries with low-R&D intensity, where research institutes play a large role in total R&D. It is a system where private innovators are not very developed, and are low-profile innovators. The role of the government in this system is an organizing one, focusing on the research institutes sectors and on specific topics, because of the weakness of the other actors in the system.

Tables 7.2.1 and 7.2.2 characterize the innovation system in the different Member States around three key actors: Universities, institutes and firms :

- Twelve of the countries has at least one weak sector. These are Bulgaria, Croatia, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Romania, Slovakia and Spain, where the research institutes sector has a larger role. Verspagen *et al.* (2017a, *ibid*) characterize these systems as developing and institute driven. “*In Cyprus and Ireland, none of the sectors take a leading role, we characterize these systems as just developing. In Portugal, the private enterprise sector takes the leading role, we characterize this as a developing system with a leading firm role*” (Verspagen *et al.*, 2017a, *ibid*, page 38).
- In the other countries, there are multiple sectors that perform strongly. Verspagen *et al.* (*ibid*) call the Netherlands and Sweden systems, where there is no tendency for a specific role in each of the three sectors, “*strong and broad*”. Belgium is also close to this, but with an industry driven research institutes sector, and this system can be characterized as “*broad and industry*”. Germany is both industry driven and science-based.

Table 7.2.1 – European innovation systems, synthesis (1/2)

	Higher education	Institutes	Firms	Overall
Austria	Industry oriented, otherwise low	Weak, industry-oriented	Strong and broad	Industry oriented
Belgium	Good-Excel allover	Industry oriented	Strong and broad	Broad and industry driven
Bulgaria	Not ranked (low)	Industry and research oriented	Weak with a tendency for external sourcing	Developing and institutes driven
Croatia	Not ranked (low)	Research oriented	Externally driven	Developing and institutes driven
Cyprus	Research oriented, otherwise low	Weak and research oriented	Supply-chain and externally driven	Developing
Czech Republic	Low	Strong and broad	Supply-chain driven	Tending towards demand driven
Denmark	Very good, especially research	Weak and public oriented	Supply-chain driven	Demand driven
Estonia	Low-Av	Research oriented	Supply-chain and externally driven	Tending towards demand driven
Finland	Broadly Av, with pockets of excellence	Strong and industry oriented	Strong and broad	Industry oriented
France	Av with pockets of excellence, low industry interaction	Strong and public (defense) oriented	Average and non-specialized	Public driven
Germany	Excel allover	Strong and industry oriented	Strong and Science-based	Industry driven and science-based
Greece	Low-Av	Broad	Supply-chain and externally driven	Developing and institutes driven
Hungary	Low	Research oriented	Weak with a tendency for external sourcing	Developing and institutes driven
Ireland	Low-Av, research oriented	Weak and industry oriented	Average and non-specialized	Developing
Italy	Low	Public and industry oriented	Average and non-specialized	Developing and institutes driven

Source: Adapted from Verspagen et al. (2017a, [328])

- The other countries have strong systems, but with an emphasis on one aspect. Finland is industry-driven, and Denmark demand-driven. France and UK are driven by public interest issues, defense

Table 7.2.2 – European innovation systems, synthesis (2/2)

	Higher education	Institutes	Firms	Overall
Latvia	Low	Industry oriented	Weak with a tendency for external sourcing	Developing and institutes driven
Lithuania	Industry oriented, otherwise low	Research oriented	Average with a tendency for external sourcing	Developing and institutes driven
Luxem-bourg	Research oriented, otherwise low	Strong and public oriented	Average and non-specialized	Developing and institutes driven
Malta	Not ranked (low)	Weak and industry/public oriented	Average and non-specialized	Developing and institutes driven
Netherlands	Excel allover	Broad	Strong and broad	Broad and strong
Poland	Low	Public (defense) oriented	Weak with a tendency for external sourcing	Developing and institutes driven
Portugal	Av, industry oriented	Weak and public oriented	Strong and broad	Developing and firm driven
Romania	Low-Av	Research oriented	Weak with a tendency for external sourcing	Developing and institutes driven
Slovakia	Low	Strong and broad	Weak with a tendency for external sourcing	Developing and institutes driven
Slovenia	Low-Av	Strong and research oriented	Strong and broad	Developmental and institutes driven
Spain	Low	Public oriented	Weak	Institutes driven
Sweden	Good-Excel allover	Weak and research oriented	Strong and broad	Broad and strong
United Kingdom	Av with pockets of excellence, low industry interaction	Public (defense) oriented	Strong and broad	Broad with emphasis on defence

Source: Adapted from Verspagen et al. (2017a, [328])

in the UK. Finally, Slovenia is “developmental”, as it has a strong and broad private enterprise sector, supported by a strong, oriented research institutes sector.

7.2.1.2 Characterization of Member States Innovation Systems by adding information on Member States' innovation policies

Introducing the role played by the Member States innovation policies in the analysis, following (Bemelmans-Vidéc *et al.* 2003, [27]) and Borrás and Edquist (2013, [35]) Verspagen *et al.* (2017b, [329]) we discern three categories of policy instruments: Economic and financial instruments, regulatory instruments and soft instruments (See table 7.2.3).

Table 7.2.3 – Public policy instruments and their characterization

No.	Financial instruments	Regulatory instruments	Soft instruments
1	"En block" support to universities & other RO's	Competition (anti-trust) policy regulations concerning R&D	
2	Cash grants & competitive research funding	Other government regulations concerning RDI	Codes of conduct
3	Government provision of goods & services	Regulation of intellectual property rights	Contractual relations - commitments towards
4	Loan guarantees	Regulation of universities/higher education/PRO's: Researchers' employment regulation	Monitoring , evaluation of policies and instruments
5	Participation in European Research Infrastructures or other international collaborations	Regulation of universities/higher education/PRO's: statutes	Public-private partnerships to share risk, costs, benefits
6	Private provision of goods & services under government contracts		Recommendations
7	Public procurement		Voluntary agreements
8	Reduced interest loans		Voluntary technical standards
9	Subsidies		
10	Support to technology transfer		
11	Support to ventures & seed capital		
12	Support to ventures & seed capital		

Source: Adapted from Verspagen et al. (2017b, [329])

The economic and financial instruments include the funding of Universities, all sorts of incentives to firms such as subsidies, tax credits, reduced interest loans and public procurements. Regulatory instruments include for example the legal regulation of Universities and of intellectual property rights,

such as patents, trademarks and copyrights. Finally, soft instruments complement the two other categories by orienting the practices in the innovation system toward specific goals (e.g. public-private partnerships in specific technological areas, technical standards, voluntary agreements) including the evaluation and the monitoring of the system.

Verspagen *et al.* (2017b, [329]) distinguish, in all 26 policy instruments with data on their implementation in the 28 Member States, allowing a mapping of the different countries in the policy space to arrive to a more complete characterization of the Member States' innovation systems. On this basis, the authors distinguish four main groups of innovation systems to be found in European Union countries:

1. First there is first the *Strongly Developed* group that consists in a number of countries that are generally highly developed in the economic sense. They are Austria, Belgium, Denmark, Finland, Germany, the Netherlands, Slovenia, Sweden, and the United Kingdom. There are all countries where the innovation system is strongly developed and performs well in an international context. There are two exceptions to this rule, with Slovenia that has a weaker University system, and Austria with a weaker role in the public policy and institutes sector. Several national specificities also emerge from the analysis. For example, Germany puts a strong emphasis on science-based innovation, supported by strong universities and industry-oriented institute sectors. In Finland, the institutes sector and public policies are strongly firms' interests oriented, while in Denmark firms are supply-chain driven innovators. In the United Kingdom, there is a strong defense and private firms' orientation. Finally for the other countries, Belgium, the Netherlands and Sweden, the authors do not find any particular patterns and instead balanced systems.
2. The second group of countries is characterized as *Publicly policy-led* innovation systems. It includes France, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta and Portugal, where innovation in the private sector (firms) is not particularly well developed, contrary to public policy in the STI field that is developed and active. Therefore in this group of countries, innovation arises more often from public policy. National specificities that emerge are the orientation of public policy toward market-based innovation in Ireland, Latvia, Luxembourg and Malta, and the public and semi-public research tendency of public policy in France and Lithuania. In Portugal and Italy, the situation is more balanced.

(a) The third group of countries are *characterized as Developing* innovation systems, that in-

clude Bulgaria, Croatia, Cyprus, Czech Republic, Hungary, Romania, Slovakia and Spain. In these systems, innovation is strongly dependent on external knowledge and competencies, such as supply-chain based innovation and external sourcing. This particular style of innovation in the firms' sector forces public policy to be aimed at absorption by the private sector. It typically comes from semi-public research in the institutes sector, while the university system tends to be weak.

3. The last group is the *Lagging behind* group. There are three countries in it: Estonia, Greece and Poland. Firms are either supply-chain driven innovators, or externally sourcing (as in the previous group), but public policy is comparatively weak.

7.2.1.3 Introducing the specific context of the Innovation Union and its 34 commitments¹¹

In the specific context of the Innovation Union and its 34 commitments, regarding the large heterogeneity of innovation systems in EU Member states, it is expected that the commitments will have very varied impacts on innovative activity in the different groups of countries. Therefore, for the large number of countries that are not in an *advanced system* category, with elements of their innovation system that are weakly developed, it is expected that policy actions (commitments) focusing at reinforcing certain actors in that system could in time, if implemented with sufficient intensity, lead to less heterogeneity between the development levels of the innovation systems in the EU. On the other hand, as Verspagen *et al.* (2017, [329]) stress, “(...) *policy actions aimed at general conditions for innovation, or at removing obstacles for innovation, may reinforce the differences between member states, because they provide better opportunities for innovation actors in systems that are already well-developed*” (Verspagen *et al.*, 2017b, *ibid*, pages 17-18).

For illustration, ERA policies aiming at improving the mobility of researchers, may not be very effective in countries where the innovation system is mainly focused on the absorption of external source of knowledge, because firms do not use research as their main source of innovation. Policies in this category would be therefore more effective if combined with policies from the first category above, aiming at reinforcing the research system and the scientific basis in these countries.

To continue with the detail of the different commitments, and take stock of the work achieved

¹¹The content in this section is mainly based on the I3U policy brief of September 2018, [168]).

by the commitments' experts team on the commitments implementation, the first statement is that “(...) *the commitments of the Innovation Union have to a considerable degree been implemented and yielded the desired effects*” (See I3U, 2018, [168]). For example, there was an increase in the number of innovations coming from the KICs, in the number of start-ups created, and the number of graduates in EIT. Access to finance of innovators was also improved, with the introduction by the EU commission of a number of policies as InnovFin, European Venture Capital (EuVECA) Funds, and the revision of the General Block Exemption Regulation (GBER). European Innovation Partnerships (EIP) targeting global challenges were also implemented, creating linkages between innovation actors, and facilitating knowledge spillovers.

However the actions connected to the different commitments were implemented to various degrees. Knowledge alliances and partnerships between business and academia (Commitment 2) were more developed in Nordic and Central European countries, as a result of the characteristics of their innovation systems. Commitment C30, for attracting and retaining foreign talent, was only partially implemented, and the share of third country migrant workers with high skills is still low. Venture capital funds (Commitment 11) are mainly marketed in fifteen countries. The European patent (Commitment 14) is not implemented yet and pre-commercial procurements for innovative products are just beginning (Commitment 17). The role of Technology Transfer Office in Europe is limited (Commitment 21), and the European market for technologies remains under-developed (Commitment 22). The share of Structural funds for R&I (Commitment 24) decreased sharply between FP7 and H2020 and should not increase under Horizon Europe. Inclusive innovation (Commitment 28) is still not truly effective due to various deficiencies. Scientific cooperation projects with third countries (Commitment 31) are still bilateral and have declined from the FP7 to H2020.

The projection of the 34 commitments in the Conceptual Model of the EU Innovation systems from the inputs provided by the commitments' expert teams, confirms that two categories of commitment can be distinguished: “*On the one hand, we have those that are unequally aimed at the innovation systems that are found in the European Union, and therefore they may lead to either convergence of innovation systems, when the weaker systems are more positively affected than the stronger, or to a divergence in the opposite case. On the other hand, there are commitments or policy actions that affect all innovation systems in the European Union and are therefore not expected to lead to either divergence or convergence of innovation systems in Europe.*” (I3U, 2018, [168]).

On one hand, there are therefore 14 commitments (1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 15, 21, 30 and

31) for which there is a potential for greater divergence between the “strongly developed” innovation systems in Europe and the “developing or lagging behind” innovation systems. The reason is that they tend to mainly affect strong performers, such as science-based firms, or research-driven universities, and concern actors that are more concentrated in strongly developed innovation systems. It is the case for example for University ranking (Commitment 2), the increase in the number of PhD students (Commitment 1), the opportunities offered by the research area (Commitment 4), the funds spent on research infrastructures that go toward strongly developed structures (Commitment 5), the concentration of R&I FP funding (Commitment 6) in countries classified in the European Innovation Scoreboard as innovation leaders or strong innovators, the dichotomy between EU-15 and EU-13 countries in term of success and participation rates of SMEs to FP programmes (Commitment 7), the concentration of the innovation funding from the Risk Sharing Facility Fund (RSFF), InnovFin and European Venture Capital funds (Commitments 10, 11 and 12) on firms belonging to the most developed and public-policy led innovations systems. Similarly only countries with the most advanced innovation systems are heavily involved in international collaborations (Commitment 31) and a more conducive regulatory framework should also benefit from strongly developed innovation systems (Commitment 15).

On the other hand, we find 7 commitments (9, 16, 18, 19, 22, 23 and 25) where the weaker innovation systems are more positively affected than the strongly developed systems. This is the case for example for the Eco-Innovation Action Plan (Commitment 18) that should mainly benefit the *Developing* and *Lagging-behind* European Innovation Systems, where capability-enhancing initiatives have the strongest effects. The implementation of the market for patents and licenses (Commitment 22) should also provide more opportunities for lagging behind ecosystems to catch-up, if there is a strong enough absorption capacity. The revised guideline for horizontal standardization agreements (Commitment 16) and the Block Exemption Agreement on Research and Development (Commitment 13) should also make technology transfers more efficient than previously. Finally, the European Creative Industries Alliance (Commitment 19), Smart specialization (Commitment 25) are likely “*to have the largest impact in the countries belonging to the developing and lagging innovation regimes*”.

The I3U November 2018 policy brief ([168]) concludes from the previous statements on the fact that the commitments that favor convergence are almost exclusively those that act on interactions between actors or conditions in the system: “*It thus seems that interactions and conditions are particularly useful policy targets in terms of convergence inside the Innovation Union, while especially policy actions aimed at capabilities of actors seem to be leading to divergence. By focusing more explicitly on the capabilities*

of actors in lagging or developing innovation systems, this tendency could certainly be reversed, but in the current Innovation Union, capabilities of advanced actors seem to be more often targeted”.

Concerning the implications for macroeconomic modeling of the European Innovation systems using NEMESIS, first Mohnen ([241]) summarized them as well as the list of the commitments that could/should be implemented in the NEMESIS model, that have resulted in the tables 7.1.2, 7.1.3 and 7.1.4 above. Taking into account the previous two points, the model should be calibrated or estimated in such a way as to show the specificities in the innovation systems of the different Member States, in order to allow model builders to make their models more relevant by obtaining the “*differentiated impact*” of the commitments on innovation and R&D in the different Member States, leading to a more realistic analysis of R&D and innovation using the model.

7.2.2 The progress of the Innovation Union as Measured by the European Innovation Scoreboard

This section now extends this analysis of the progress made by the Innovation Union using the results of the European Innovation Scoreboard¹² (Le Mouël, 2017, [210]).

The European Innovation Scoreboard¹³ (EIS thereafter) measures the innovation performance of the European Union based on three main types of indicators and eight innovation dimensions, for a total of 25 different indicators¹⁴ .

1. Enabler indicators capture a firm’s main external drivers for innovation performance and differentiate between three innovation dimensions: (1) The Human Resources Dimension, which includes three indicators and measures the availability of a high-skilled and educated workforce, (2) The Open, Excellent and Attractive research systems dimension, which includes three indicators and measures the international competitiveness of the science base, and (3) The Finance and Support dimension, with two indicators that measure the availability of finance for innovation projects and the support of governments for research and innovation activities.
2. Firm activities indicators capture the innovation efforts at the level of the firm and differentiate between three innovation dimensions: (4) The Firm Investments Dimension, with two indica-

¹²The study we present in this section was made in February 2017. The 2017 and 2018 editions of the EIS are now available: http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en

¹³The EIS took this new name in 2016. It was called from 2010 to 2015 Innovation Union Scoreboard.

¹⁴See, “European Innovation Scoreboard 2016. Methodology report”.

tors that cover both R&D and non-R&D investments, (5) The Linkages & Entrepreneurship dimension, which includes three indicators and measures entrepreneurial efforts and collaboration efforts among innovating enterprises (including relationships with the public sector) and (6) The Intellectual Assets Dimension, addressing different forms of Intellectual Property Rights (IPR) generated as a throughput in the innovation process.

3. Output indicators capture the effects of enterprises' innovation activities and differentiate between two innovation dimensions: (7) The Innovators Dimension, which includes three indicators and measures the number of enterprises that have introduced innovations for the market or within their organizations, covering both technological and non-technological innovations, (8) The Economic Effects Dimension, which includes five indicators and captures the economic success of innovation in employment, exports, and sales.

7.2.2.1 Situation in 2015: Country ranking

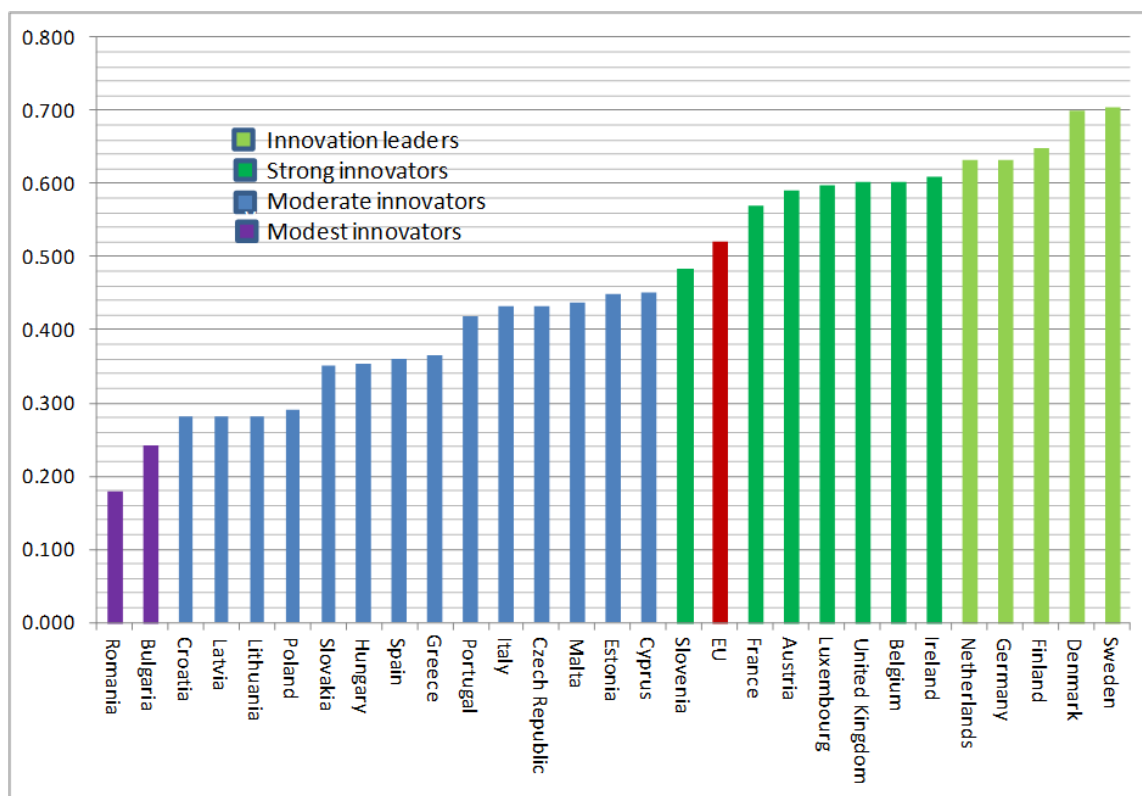
The relative innovation performance of Member States is summarized by a composite indicator (Cf. figure 7.2.1), the Summary Innovation Index (SII), which averages the three main types of indicators listed above (Enablers, Activities, Outputs).

Four categories of innovators are distinguished:

1. Innovation leaders, with a SII at least 20% above the EU average (Denmark, Finland, Germany, the Netherlands, and Sweden).
2. Strong innovators, with a SII between 90% and 120% of the EU average (Austria, Belgium, France, Ireland, Luxembourg, Slovenia, and the UK).
3. Moderate innovators, with a SII between 50 % and 90 % of the EU average (Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Slovakia, and Spain).
4. Modest innovators with a SII below 50% of the EU average (Bulgaria and Romania).

EIS 2016 does not show any major changes in these “*performance group memberships*”, compared to the 2015 report. Only Latvia has moved up to become a moderate innovator while the Netherlands joined the Innovation leaders.

Figure 7.2.1 – Relative innovation performance of Member States measured by the SII for 2015.



Source: Based on EIS 2016 data

When looking more closely at the values of the eight categories of indicators in the SII (table 7.2.4), the countries classified as modest and moderate innovators generally exhibit the lowest scores for all indicators (lower than 0.4 – red diamonds – or between 0.4 and 0.6 – yellow triangles). Conversely, countries classified as strong innovators or innovation leaders generally score above 0.6 (green circles) or close to 0.6 for all indicators. The only exception is for the Human Resources indicator, that measures the share of high-skilled and educated workers, even though, on average, the best performing countries have higher scores than the less performing ones.

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Table 7.2.4 – Values of indicators for the eight innovation dimensions for 2015

	Summary Innovation Index	Enablers			Firms activity			Outputs	
		Human resources	Research systems	Finance and support	Firm investments	Linkages & entrepreneurship	Intellectual assets	Innovators	Economic effects
Romania	0.18	0.39	0.11	0.07	0.08	0.04	0.15	0.19	0.27
Bulgaria	0.24	0.50	0.09	0.10	0.21	0.07	0.50	0.19	0.18
Croatia	0.28	0.61	0.16	0.29	0.32	0.27	0.22	0.19	0.25
Latvia	0.28	0.53	0.17	0.42	0.43	0.10	0.33	0.11	0.25
Lithuania	0.28	0.73	0.13	0.54	0.35	0.17	0.26	0.11	0.17
Poland	0.29	0.56	0.12	0.27	0.36	0.09	0.39	0.21	0.30
Slovakia	0.35	0.64	0.17	0.25	0.27	0.21	0.24	0.42	0.49
Hungary	0.35	0.46	0.22	0.27	0.37	0.21	0.28	0.32	0.57
Spain	0.36	0.45	0.41	0.36	0.18	0.24	0.44	0.25	0.43
Greece	0.36	0.56	0.41	0.22	0.28	0.41	0.24	0.47	0.32
Portugal	0.42	0.59	0.45	0.47	0.26	0.38	0.38	0.51	0.33
Italy	0.43	0.41	0.40	0.28	0.28	0.42	0.50	0.58	0.46
Czech Republic	0.43	0.56	0.30	0.45	0.40	0.42	0.34	0.47	0.51
Malta	0.44	0.27	0.26	0.10	0.42	0.28	0.64	0.62	0.60
Estonia	0.45	0.55	0.34	0.73	0.55	0.46	0.43	0.42	0.32
Cyprus	0.45	0.66	0.39	0.28	0.15	0.45	0.40	0.62	0.48
Slovenia	0.48	0.83	0.39	0.24	0.47	0.58	0.48	0.42	0.42
EU	0.52	0.58	0.47	0.49	0.43	0.47	0.56	0.53	0.57
France	0.57	0.66	0.68	0.57	0.36	0.50	0.49	0.66	0.58
Austria	0.59	0.65	0.56	0.54	0.52	0.63	0.71	0.65	0.47
Luxembourg	0.60	0.43	0.77	0.37	0.14	0.54	0.72	0.70	0.74
United Kingdom	0.60	0.79	0.80	0.51	0.27	0.59	0.50	0.52	0.68
Belgium	0.60	0.62	0.77	0.50	0.49	0.81	0.49	0.57	0.56
Ireland	0.61	0.82	0.58	0.36	0.30	0.59	0.43	0.77	0.78
Netherlands	0.63	0.65	0.77	0.66	0.24	0.73	0.62	0.54	0.68
Germany	0.63	0.57	0.44	0.56	0.75	0.62	0.70	0.76	0.63
Finland	0.65	0.78	0.63	0.77	0.50	0.68	0.72	0.59	0.56
Denmark	0.70	0.70	0.77	0.65	0.46	0.77	0.79	0.62	0.71
Sweden	0.70	0.83	0.81	0.71	0.62	0.69	0.73	0.64	0.62

Source: Based on EIS 2016 data

Table 7.2.5 – Linear correlation across countries between the eight categories of innovation indicators for 2015

	Summary Innovation Index	Human resources	Research systems	Finance and support	Firm investments	Linkages & entrepreneurship	Intellectual assets	Innovators	Economic effects
Summary Innovation Index	1.00	0.51	0.92	0.70	0.47	0.95	0.82	0.86	0.84
Human resources	0.51	1.00	0.45	0.55	0.32	0.54	0.18	0.24	0.23
Research systems	0.92	0.45	1.00	0.64	0.20	0.90	0.70	0.74	0.77
Finance and support	0.70	0.55	0.64	1.00	0.56	0.67	0.52	0.38	0.36
Firm investments	0.47	0.32	0.20	0.56	1.00	0.45	0.45	0.30	0.18
Linkages & entrepreneurship	0.95	0.54	0.90	0.67	0.45	1.00	0.70	0.80	0.72
Intellectual assets	0.82	0.18	0.70	0.52	0.45	0.70	1.00	0.68	0.64
Innovators	0.86	0.24	0.74	0.38	0.30	0.80	0.68	1.00	0.82
Economic effects	0.84	0.23	0.77	0.36	0.18	0.72	0.64	0.82	1.00

Source: Based on EIS 2016 data

These observations are confirmed by the values of the linear correlation coefficients between the different indicators calculated across countries (table 7.2.5). The strong correlation of the individual indicators with the SII, generally higher than 0.66 (green circles) with several even higher than 0.8, confirms that countries with high SII values generally exhibit high scores for all the indicators and

conversely. The exceptions concern the Human capital indicators (correlation coefficient 0.51) and the Firms investments indicator (correlation coefficient 0.47).

In particular, this last result is more surprising as Firms investment covers two Enablers that measure the diffusion of new production technologies and ideas: Private R&D investment in % of GDP (from EUROSTAT) and firms' investments in other innovation assets in % of turnover (from CIS: Community Innovation Survey), such as the purchase of innovative equipment and machines, of patents and licenses. The reason may be that R&D investments mainly concern industrial firms or near to science sectors, such as chemicals and electronics, whereas the EIS covers all types of innovations (technological and non-technological such as organizational innovations) in all sectors (industry, services and agriculture). The correlation between the other innovation dimensions is confirmed as very strong, higher than or close to 0.66, with few exceptions.

7.2.2.2 Evolution from 2008 to 2015

Let's now look at the evolution between the 2008 financial crisis and 2015. Table 7.2.6 shows the dynamics (in % change) of the SII and of the 8 categories of indicators between these two dates.

While few changes occurred over the period in the country ranking (only Croatia and Latvia moved up to moderate innovators and Cyprus moved down to moderate innovator), the evolution between countries is highly contrasted. As a whole, the SII increased by 5.3%, but the spectrum of individual evolution ranges from -26.9% in Romania, the worst performing country in 2015, to +31.5% in Latvia, still a very moderate innovator compared to the EU average. Most countries experienced a positive dynamic, with improvements above 5% for 16 countries (green circles), with 6 other countries exhibiting variations between 0% and 5% (yellow triangles), while negative variations have been reported only for 6 countries (red diamonds).

For most countries, the SII index was pushed up by the rise of two Enablers, Human resources and Research systems, which include indicators such as the number of scientific publications and of doctoral graduates.

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Table 7.2.6 – Evolution of SII and of the eight innovation indicators categories between 2008 and 2015 (in %)

	Summary Innovation Index	Human resources	Enablers		Firms activity			Outputs		Economic effects
			Research systems	Finance and support	Firm investments	Linkages & entrepreneurship	Intellectual assets	Innovators		
Romania	⬇️ -26.9%	⬆️ 56.1%	⬆️ 16.2%	⬇️ -76.8%	⬇️ -74.0%	⬇️ -72.1%	⬆️ 10.2%	⬇️ -39.7%	⬇️ -27.0%	
Bulgaria	⬆️ 10.2%	⬆️ 27.8%	⬇️ -48.7%	⬇️ -67.0%	⬇️ -7.7%	⬇️ -46.8%	⬆️ 108.7%	⬆️ 19.5%	⬇️ -0.5%	
Croatia	⬇️ -6.2%	⬆️ 15.0%	⬆️ 24.3%	⬆️ 24.6%	⬆️ 14.4%	⬇️ -30.2%	⬇️ -3.2%	⬇️ -36.3%	⬇️ -18.8%	
Latvia	⬆️ 31.5%	⬆️ 74.0%	⬆️ 97.6%	⬆️ 56.0%	⬆️ 18.9%	⬇️ -24.9%	⬆️ 15.2%	⬆️ 33.7%	⬆️ 14.6%	
Lithuania	⬆️ 18.0%	⬆️ 33.1%	⬆️ 63.2%	⬆️ 103.9%	⬆️ 75.3%	⬇️ -38.4%	⬆️ 49.2%	⬇️ -51.3%	⬇️ -15.4%	
Poland	⬆️ 0.7%	⬆️ 11.8%	⬆️ 22.9%	⬆️ 28.0%	⬆️ 27.4%	⬇️ -60.7%	⬆️ 51.1%	⬇️ -39.5%	⬇️ -9.3%	
Slovakia	⬆️ 10.2%	⬆️ 43.9%	⬆️ 26.2%	⬆️ 223.8%	⬇️ -41.1%	⬇️ -18.2%	⬆️ 30.3%	⬆️ 0.4%	⬆️ 2.1%	
Hungary	⬆️ 2.8%	⬆️ 37.9%	⬆️ 3.6%	⬇️ -1.0%	⬆️ 32.0%	⬇️ -11.6%	⬇️ -3.4%	⬇️ -2.1%	⬇️ -6.5%	
Spain	⬇️ -5.2%	⬆️ 51.7%	⬆️ 3.6%	⬇️ -27.1%	⬇️ -31.6%	⬇️ -22.6%	⬆️ 5.1%	⬇️ -38.7%	⬆️ 1.7%	
Greece	⬇️ -1.5%	⬆️ 32.4%	⬆️ 29.6%	⬆️ 22.6%	⬆️ 22.2%	⬇️ -16.4%	⬆️ 34.3%	⬇️ -17.5%	⬇️ -27.8%	
Portugal	⬆️ 6.5%	⬆️ 29.3%	⬆️ 62.1%	⬇️ -5.2%	⬇️ -28.6%	⬇️ -2.4%	⬆️ 15.1%	⬇️ -10.6%	⬇️ -0.9%	
Italy	⬆️ 11.2%	⬆️ 33.9%	⬆️ 47.9%	⬇️ -11.1%	⬆️ 4.9%	⬆️ 5.0%	⬇️ -1.0%	⬆️ 10.0%	⬆️ 12.0%	
Czech Republic	⬆️ 5.1%	⬆️ 16.3%	⬆️ 46.5%	⬇️ -30.7%	⬆️ 6.2%	⬇️ -8.1%	⬆️ 18.4%	⬆️ 1.8%	⬆️ 10.1%	
Malta	⬆️ 27.8%	⬆️ 138.1%	⬆️ 9.6%	⬆️ 111.7%	⬆️ 16.3%	⬆️ 17.1%	⬆️ 119.5%	⬆️ 56.2%	⬇️ -16.4%	
Estonia	⬆️ 7.7%	⬆️ 30.1%	⬆️ 56.6%	⬆️ 118.6%	⬇️ -6.6%	⬇️ -28.6%	⬆️ 48.8%	⬇️ -29.5%	⬇️ -8.4%	
Cyprus	⬇️ -3.9%	⬆️ 20.6%	⬆️ 80.4%	⬇️ -5.0%	⬇️ -70.3%	⬇️ -30.9%	⬆️ 8.9%	⬇️ -9.1%	⬆️ 3.9%	
Slovenia	⬆️ 8.6%	⬆️ 53.8%	⬆️ 34.9%	⬇️ -18.8%	⬇️ -27.8%	⬆️ 0.9%	⬆️ 15.7%	⬇️ -6.0%	⬆️ 3.1%	
EU	⬆️ 5.3%	⬆️ 26.9%	⬆️ 14.8%	⬇️ -6.5%	⬆️ 16.1%	⬆️ 1.8%	⬆️ 0.4%	⬇️ -9.2%	⬆️ 7.0%	
France	⬆️ 5.4%	⬆️ 14.4%	⬆️ 14.7%	⬇️ -7.1%	⬆️ 2.7%	⬇️ -6.5%	⬇️ -1.5%	⬆️ 14.1%	⬆️ 6.5%	
Austria	⬆️ 1.5%	⬇️ -1.6%	⬆️ 36.1%	⬆️ 26.0%	⬆️ 16.5%	⬇️ -15.1%	⬆️ 2.4%	⬇️ -9.0%	⬇️ -4.3%	
Luxembourg	⬇️ -5.4%	⬆️ 8.3%	⬆️ 96.6%	⬇️ -43.0%	⬇️ -72.8%	⬇️ -14.9%	⬆️ 6.7%	⬇️ -23.6%	⬇️ -1.0%	
United Kingdom	⬆️ 14.7%	⬆️ 35.4%	⬆️ 13.8%	⬇️ -26.0%	⬆️ 2.2%	⬆️ 41.3%	⬆️ 3.3%	⬆️ 39.2%	⬆️ 11.3%	
Belgium	⬆️ 6.7%	⬆️ 13.1%	⬆️ 34.8%	⬇️ -21.1%	⬆️ 31.4%	⬆️ 8.5%	⬇️ -0.6%	⬇️ -14.3%	⬆️ 10.5%	
Ireland	⬆️ 4.2%	⬆️ 15.3%	⬆️ 23.4%	⬇️ -37.7%	⬇️ -27.2%	⬆️ 4.5%	⬇️ -1.1%	⬆️ 3.3%	⬆️ 14.2%	
Netherlands	⬆️ 15.1%	⬆️ 32.6%	⬆️ 19.2%	⬇️ -3.0%	⬆️ 3.9%	⬆️ 23.2%	⬆️ 3.5%	⬆️ 23.3%	⬆️ 14.6%	
Germany	⬆️ 1.2%	⬆️ 20.3%	⬆️ 6.8%	⬆️ 14.4%	⬆️ 33.5%	⬇️ -3.3%	⬇️ -7.3%	⬇️ -12.5%	⬇️ -3.2%	
Finland	⬇️ -2.0%	⬇️ -2.4%	⬆️ 53.9%	⬇️ -9.2%	⬇️ -18.2%	⬇️ -23.4%	⬆️ 11.7%	⬇️ -9.5%	⬇️ -1.8%	
Denmark	⬆️ 12.3%	⬆️ 74.1%	⬆️ 19.2%	⬆️ 3.0%	⬇️ -0.7%	⬆️ 8.8%	⬇️ -5.9%	⬇️ -9.9%	⬆️ 30.8%	
Sweden	⬆️ 1.0%	⬆️ 5.0%	⬆️ 44.6%	⬇️ -17.9%	⬇️ -1.8%	⬇️ -11.6%	⬇️ -2.9%	⬇️ -5.6%	⬆️ 3.5%	

Source: Based on EIS 2016 data

As for the other groups of innovation indicators, the Output indicators group features noteworthy improvements in Intellectual assets in most countries ranked as modest and moderate innovators, although this indicator shows a great variability among innovation leaders and strong innovators. The contrary is observed for Economic effects indicator, which increases in most innovation leaders and strong innovator countries, while decreasing for most of the low ranked countries.

In more detail, Table 4 shows the linear correlations between the SII and the eight categories of innovation indicators over the period 2008-2015. Despite the increase in most countries in the Indicator Human Resources, which pushed up the SII at EU-28 level, it was in fact only barely correlated (positively) to the evolution of the SII (correlation coefficient 0.08) as well as to all other innovation categories (correlation coefficient between -0.19 – for Firms investment - and +0.26 – for finance and support). All other indicators are quite strongly – positively - correlated with the SSI (correlation coefficient between 0.33 and 0.66, in yellow triangles).

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Table 7.2.7 – Linear correlation across countries between the evolution of the eight categories of innovation indicators on the 2008-2015 period

	Summary Innovation Index	Human resources	Research systems	Finance and support	Firm investments	Linkages & entrepreneurship	Intellectual assets	Innovators	Economic effects
Summary Innovation Index	1.00	▲ 0.48	◆ 0.08	▲ 0.46	▲ 0.50	▲ 0.50	▲ 0.37	▲ 0.66	▲ 0.42
Human resources	▲ 0.48	1.00	◆ -0.15	◆ 0.32	◆ 0.02	◆ 0.18	▲ 0.46	▲ 0.42	◆ -0.04
Research systems	◆ 0.08	◆ -0.15	1.00	◆ 0.17	◆ -0.19	◆ -0.05	◆ -0.27	◆ -0.17	◆ 0.08
Finance and support	▲ 0.46	◆ 0.32	◆ 0.17	1.00	◆ 0.26	◆ -0.02	▲ 0.34	◆ 0.04	◆ -0.19
Firm investments	▲ 0.50	◆ 0.02	◆ -0.19	◆ 0.26	1.00	◆ 0.18	◆ 0.13	◆ 0.06	◆ -0.06
Linkages & entrepreneurship	▲ 0.50	◆ 0.18	◆ -0.05	◆ -0.02	◆ 0.18	1.00	◆ -0.26	▲ 0.62	▲ 0.56
Intellectual assets	▲ 0.37	▲ 0.46	◆ -0.27	▲ 0.34	◆ 0.13	◆ -0.26	1.00	◆ 0.24	◆ -0.39
Innovators	▲ 0.66	▲ 0.42	◆ -0.17	◆ 0.04	◆ 0.06	▲ 0.62	◆ 0.24	1.00	▲ 0.41
Economic effects	▲ 0.42	◆ -0.04	◆ 0.08	◆ -0.19	◆ -0.06	▲ 0.56	◆ -0.39	▲ 0.41	1.00

Source: Based on EIS 2016 data

Among the eight innovation dimensions, the strongest positive correlations are found between Linkage and entrepreneurship one on hand and Innovators and Economic effects on the other, with correlation coefficients respectively at 0.62 and 0.56. Other strong correlations (> to 0.25) are found between:

- Human resources and: Finance and Support (0.32) - Intellectual assets (0.46) - Innovators (0.42);
- Finance and support and: Firms investments (0.26) - Intellectual assets (0.34).

Surprisingly, the Research systems group of indicators, which in 2015 was strongly correlated with the other groups of indicators and the country ranking, appears to be less correlated to the other groups, in most of cases with inverse correlations, with reference to the evolution from 2008 to 2015 of performance indicators. This could mean that the period under examination (2008-2015) is too short to show clear trends, and that the economic crisis may have contributed to make correlations less significant.

7.2.2.3 The specific contribution of R&D investments

It is commonly acknowledged¹⁵ that R&D investments, public and private, are among the major drivers of economic growth in knowledge based economies. Although the EIS 2016 does not focus on the specific influence of the R&D intensity on the relative innovation performance of EU countries, it nevertheless recognizes that “As such, trends in the R&D expenditure indicator provide key indications of the future competitiveness and wealth of the EU. Research and development spending is essential for

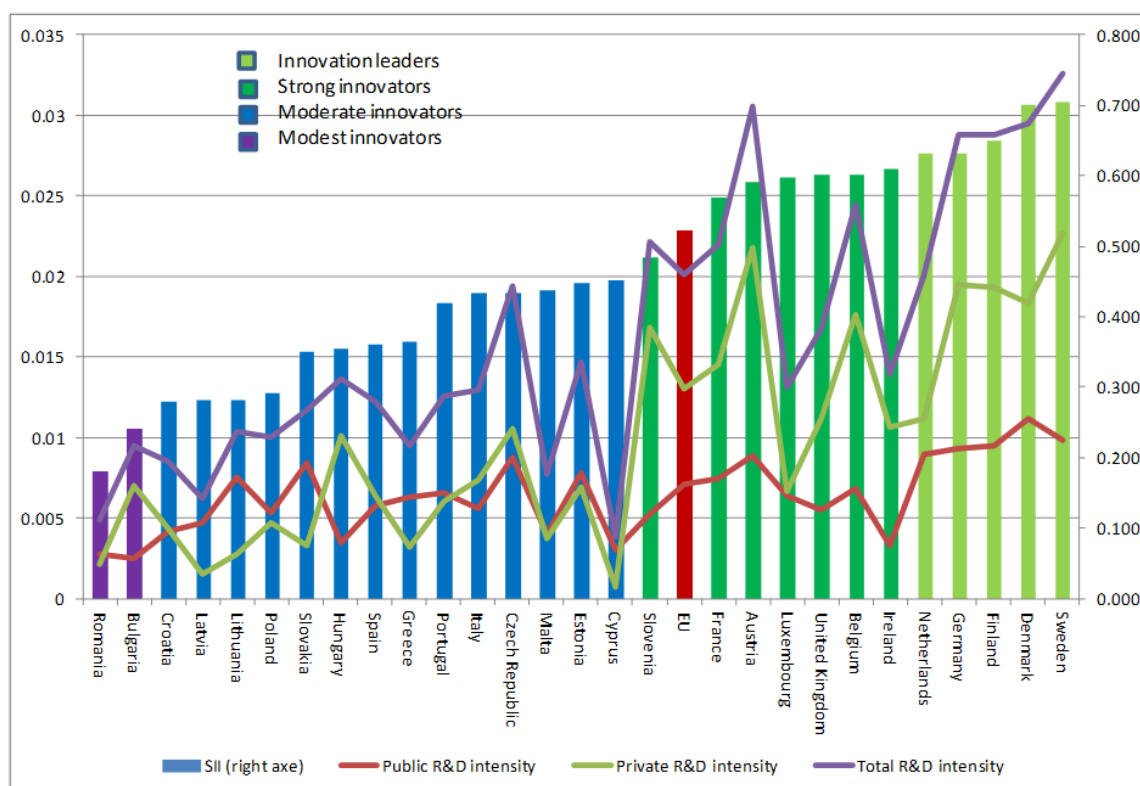
¹⁵ e.g. OECD “Knowledge based economy”, Paris, 1996.

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making the transition to a knowledge-based economy as well as for improving production technologies and stimulating growth”.

This statement is confirmed by figure 7.2.2 that shows a strong correlation between the level of the public, private and total R&D intensity in % GDP at country level, and the innovation performance ranking for 2015, as captured by the SII.

Figure 7.2.2 – Country ranking (SII) and relative R&D intensity in % GDP in 2015



Source: Based on EIS 2016 data and EUROSTAT (for R&D intensities)

The linear correlation coefficient across countries between the total R&D intensity and the value of the SII for 2015 (table 7.2.8) is equal to 0.79. Its value would even exceed 92% if we remove the very small EU countries (Malta, Cyprus, Estonia, Latvia, Lithuania, Slovenia, Croatia, Bulgaria and Luxembourg), that account together for less than 2% of EU GDP and R&D investments, and Ireland, which significantly revised (upwards) its GDP figure for 2015. For public and private R&D intensities, the correlation coefficients with the SII are respectively 0.85 and 0.70. Private R&D intensity is better correlated with the different innovation indicators, with coefficients often higher than 0.66 (green circles) or at least 0.5. The strong correlation of the private R&D intensity with the EIS innovation

indicators is sometimes not meaningful, as in the case of Firms' investments, whose value already includes the influence of private R&D intensity, as well as for other important research throughputs such as the Intellectual asset categories, which relies on the number of patent applications.

Table 7.2.8 – Linear correlation across countries between R&D intensity the eight categories of innovation indicators for 2015

	Summary Innovation Index	Human resources	Research systems	Finance and support	Firm investments	Linkages & entrepreneurship	Intellectual assets	Innovators	Economic effects
Public R&D intensity	● 0.70	▲ 0.39	▲ 0.52	● 0.80	▲ 0.57	▲ 0.60	▲ 0.53	▲ 0.40	▲ 0.34
Private R&D intensity	● 0.85	▲ 0.51	● 0.66	▲ 0.62	● 0.69	● 0.77	● 0.71	▲ 0.56	▲ 0.54
Total R&D intensity	● 0.79	▲ 0.52	● 0.68	● 0.72	● 0.71	● 0.79	● 0.72	▲ 0.56	▲ 0.53

Source: Based on EIS 2016 data and EUROSTAT (for R&D intensities)

The correlation between public R&D intensity and SII indicator is generally weaker than for private R&D intensity¹⁶. The reason behind this is that the eight innovation dimensions have strong links with market products, while public R&D activity, with a large number – about half – of its objectives focusing on the general advancement of knowledge, shows a weak and indirect link with the market.

7.2.3 How the evolution of R&D investments modified the economic performance of the EU countries?

This section again complements the analysis, by focusing more deeply on the evolution of R&D investments in the different countries between 2007 and 2015. After a presentation of these evolutions we pursue the analysis using the NEMESIS model and show how they have already modified the relative economic performance of EU countries, together with a measurement of the long-run (up to 2040) socioeconomic impacts that can be expected from these changes.

7.2.3.1 Evolution of R&D investments since the financial crisis

Globally, during the 2007-2015 period, based on EUROSTAT data and following the definitions of the Frascati manual¹⁷, the R&D intensity in the EU increases by 0.27%, with +0.18% for private R&D and 0.09% for the public R&D.

¹⁶With the exception of Finance and support which value depends on construction on the level of the public R&D intensity in % GDP.

¹⁷Total R&D investments include R&D investments in the Public sector (GOVERD and HERD) and all R&D investments in the business sector (BERD).

While over this period the EU GDP level only increases by 3.4% in real terms, the risk that the economic crisis would reduce EU Member States' R&D effort - with some MS engaged in very strong deleveraging policies - was avoided

There is no clear evidence from R&D data, or from the EIS 2016 data presented above, that the economic crisis re-enforced the double Research and Innovation divide, as stated for example by R. Veugelers in 2014 ([273]). The real danger was that a reduction in Government investments in R&D could re-enforce the differential in the Science and Innovation performance between Eastern and Western countries, and between Northern and Southern countries.

Lets now examine these evolutions in detail.

Private R&D investments Table 7.2.9 displays the evolution of private R&D intensities in EU countries. Among the 28 Member States, only 6 experiences a decrease in the R&D effort in the business sector. The greatest falls are for Luxembourg (-0.68 GDP point), Finland (-0.48 GDP point) and Sweden (-0.11 GDP point), all countries belonging to the leading group in terms of R&D intensity and ranking in the EIS.

Among the countries where the R&D effort in the business sector increases, the strongest changes are found in Slovenia (+0.83 GDP point), Bulgaria (+0.57 GDP point), Hungary (+0.53 GDP point), Belgium (+0.48 GDP point), Austria (+0.46 GDP point), Poland (+0.30 GDP point) and the Czech Republic (+0.29 GDP point). Of these seven countries, 5 are Eastern countries that score below the EU average in the EIS ranking.

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Table 7.2.9 – Evolution of private R&D intensity in % GDP in EU countries, 2007-2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
Luxembourg	1.35%	1.28%	1.30%	1.00%	0.97%	0.71%	0.69%	0.69%	0.67%	-0.68%
Finland	2.42%	2.63%	2.68%	2.59%	2.56%	2.35%	2.26%	2.15%	1.94%	-0.48%
Sweden	2.38%	2.59%	2.45%	2.21%	2.24%	2.22%	2.28%	2.11%	2.27%	-0.11%
Spain	0.69%	0.72%	0.70%	0.69%	0.69%	0.68%	0.67%	0.65%	0.64%	-0.05%
Latvia	0.18%	0.15%	0.16%	0.23%	0.19%	0.15%	0.17%	0.24%	0.15%	-0.03%
Cyprus	0.09%	0.09%	0.09%	0.08%	0.06%	0.06%	0.07%	0.08%	0.08%	-0.02%
Romania	0.22%	0.17%	0.19%	0.17%	0.18%	0.19%	0.12%	0.16%	0.21%	0.00%
Malta	0.36%	0.35%	0.33%	0.37%	0.44%	0.47%	0.40%	0.41%	0.37%	0.01%
Portugal	0.58%	0.72%	0.75%	0.70%	0.69%	0.68%	0.63%	0.60%	0.60%	0.02%
Ireland	0.81%	0.90%	1.10%	1.10%	1.07%	1.12%	1.12%	1.09%	0.86%	0.05%
Lithuania	0.23%	0.19%	0.20%	0.23%	0.24%	0.24%	0.24%	0.32%	0.28%	0.05%
Denmark	1.76%	1.94%	2.13%	1.96%	1.96%	1.95%	1.88%	1.83%	1.83%	0.07%
United Kingdom	1.02%	1.02%	1.03%	1.02%	1.07%	1.02%	1.06%	1.09%	1.12%	0.10%
Croatia	0.32%	0.39%	0.34%	0.33%	0.34%	0.34%	0.41%	0.38%	0.44%	0.12%
Italy	0.59%	0.62%	0.65%	0.66%	0.66%	0.69%	0.72%	0.76%	0.74%	0.15%
Slovakia	0.18%	0.20%	0.19%	0.26%	0.25%	0.33%	0.36%	0.32%	0.33%	0.15%
Greece	0.16%	0.21%	0.23%	0.24%	0.23%	0.24%	0.27%	0.28%	0.32%	0.15%
EU-28	1.12%	1.18%	1.19%	1.19%	1.24%	1.26%	1.29%	1.30%	1.30%	0.18%
France	1.27%	1.29%	1.36%	1.37%	1.40%	1.44%	1.45%	1.45%	1.45%	0.18%
Estonia	0.50%	0.54%	0.62%	0.79%	1.46%	1.22%	0.82%	0.63%	0.69%	0.18%
The Netherlands	0.90%	0.82%	0.79%	0.83%	1.08%	1.10%	1.09%	1.12%	1.12%	0.22%
Germany	1.71%	1.80%	1.84%	1.82%	1.89%	1.95%	1.90%	1.95%	1.95%	0.23%
Czech Republic	0.77%	0.73%	0.73%	0.77%	0.86%	0.96%	1.03%	1.10%	1.06%	0.29%
Poland	0.17%	0.19%	0.19%	0.19%	0.22%	0.33%	0.38%	0.44%	0.47%	0.30%
Austria	1.72%	1.79%	1.78%	1.87%	1.84%	2.06%	2.10%	2.16%	2.18%	0.46%
Belgium	1.28%	1.31%	1.31%	1.38%	1.48%	1.68%	1.72%	1.75%	1.77%	0.48%
Hungary	0.48%	0.52%	0.65%	0.69%	0.75%	0.83%	0.97%	0.97%	1.01%	0.53%
Bulgaria	0.13%	0.14%	0.15%	0.28%	0.28%	0.37%	0.39%	0.52%	0.70%	0.57%
Slovenia	0.85%	1.05%	1.17%	1.40%	1.79%	1.95%	1.99%	1.84%	1.69%	0.83%

Source: Eurostat

Special attention must be paid to Ireland, where the small increase in the R&D intensity (+0.05 GDP point), in fact hides a more significant increase, due to the forceful revision of the GDP calculus for 2015 (+26.3%), that in turn reflects an accounting re-estimation of the value of financial assets in GDP.

Public R&D investments The public R&D investments indicator (table 7.2.10) illustrates a fall in the intensity for seven countries, with the highest falls for Hungary (-0.11 GDP point), Ireland (-0.09 GDP point), Croatia (-0.05 GDP point), Slovenia (-0.05 GDP point), Bulgaria (-0.04 GDP point), Romania (-0.03 GDP point) and the United Kingdom (-0.02 point).

Five of these countries belong to eastern Europe, reflecting the risk of an increased European divide as underlined by R. Veugelers (2014). However, the fall of the public R&D intensity in these countries remains very limited and is largely compensated, except in Romania, by the rise of the R&D intensity in the business sector. The Irish case, here again, must be considered with caution.

Table 7.2.10 – Evolution of public R&D intensity in % GDP in EU countries, 2007-2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
Hungary	0.46%	0.45%	0.47%	0.44%	0.43%	0.42%	0.41%	0.37%	0.35%	-0.11%
Ireland	0.42%	0.49%	0.51%	0.50%	0.47%	0.44%	0.44%	0.42%	0.33%	-0.09%
Croatia	0.47%	0.49%	0.50%	0.42%	0.41%	0.41%	0.41%	0.41%	0.42%	-0.05%
Slovenia	0.57%	0.57%	0.64%	0.66%	0.63%	0.62%	0.61%	0.54%	0.52%	-0.05%
Bulgaria	0.29%	0.30%	0.34%	0.28%	0.25%	0.23%	0.24%	0.27%	0.25%	-0.04%
Romania	0.30%	0.40%	0.28%	0.28%	0.31%	0.29%	0.27%	0.22%	0.27%	-0.03%
United Kingdom	0.58%	0.58%	0.63%	0.61%	0.58%	0.56%	0.57%	0.55%	0.55%	-0.02%
France	0.72%	0.74%	0.82%	0.77%	0.76%	0.76%	0.76%	0.75%	0.74%	0.02%
Cyprus	0.28%	0.26%	0.30%	0.31%	0.32%	0.31%	0.33%	0.32%	0.31%	0.03%
Spain	0.54%	0.59%	0.65%	0.65%	0.63%	0.60%	0.59%	0.58%	0.58%	0.04%
Finland	0.91%	0.89%	1.05%	1.11%	1.05%	1.05%	1.00%	1.00%	0.95%	0.04%
Italy	0.51%	0.50%	0.53%	0.52%	0.51%	0.54%	0.55%	0.57%	0.56%	0.05%
EU-28	0.63%	0.66%	0.72%	0.72%	0.71%	0.72%	0.72%	0.72%	0.71%	0.09%
Latvia	0.37%	0.44%	0.29%	0.38%	0.50%	0.52%	0.44%	0.44%	0.47%	0.10%
The Netherlands	0.79%	0.82%	0.89%	0.90%	0.83%	0.84%	0.87%	0.88%	0.90%	0.10%
Sweden	0.87%	0.90%	1.00%	1.00%	0.99%	1.05%	1.02%	1.03%	0.99%	0.11%
Belgium	0.54%	0.59%	0.65%	0.65%	0.66%	0.68%	0.71%	0.70%	0.68%	0.14%
Poland	0.39%	0.41%	0.47%	0.53%	0.52%	0.55%	0.49%	0.50%	0.54%	0.15%
Austria	0.71%	0.78%	0.82%	0.85%	0.82%	0.85%	0.85%	0.88%	0.88%	0.17%
Lithuania	0.57%	0.60%	0.63%	0.55%	0.67%	0.65%	0.71%	0.71%	0.76%	0.19%
Germany	0.73%	0.80%	0.89%	0.89%	0.91%	0.92%	0.93%	0.94%	0.93%	0.19%
Malta	0.19%	0.18%	0.19%	0.24%	0.24%	0.35%	0.37%	0.33%	0.40%	0.21%
Portugal	0.44%	0.60%	0.69%	0.67%	0.64%	0.58%	0.68%	0.67%	0.66%	0.22%
Greece	0.40%	0.45%	0.39%	0.36%	0.43%	0.45%	0.53%	0.54%	0.63%	0.23%
Estonia	0.54%	0.69%	0.74%	0.77%	0.83%	0.88%	0.88%	0.80%	0.78%	0.24%
Czech Republic	0.53%	0.51%	0.56%	0.56%	0.69%	0.82%	0.87%	0.86%	0.88%	0.35%
Denmark	0.75%	0.83%	0.91%	0.95%	0.97%	1.01%	1.08%	1.12%	1.12%	0.38%
Luxembourg	0.26%	0.36%	0.41%	0.51%	0.50%	0.57%	0.62%	0.59%	0.64%	0.38%
Slovakia	0.27%	0.26%	0.28%	0.35%	0.42%	0.47%	0.44%	0.55%	0.84%	0.57%

Source: Eurostat

For the countries that experiences an increase in public R&D investment, the highest variations are found in Slovakia (+0.57 GDP point), Luxembourg (+0.38 GDP point), Denmark (+0.38 GDP point), Czech Republic (+0.35 GDP point), Estonia (+0.24 GDP point), Greece (+0.23 GDP point) and Portugal (+0.22 GDP point).

Of these seven countries, five are eastern or southern European countries, that rank below average in the EIS.

Total R&D investments Finally, the evolution of the total R&D intensity in the different EU Member States is displayed in table 7.2.11.

There are five countries where the R&D intensity decreases over the period 2007-2015, namely Finland (-0.45 GDP point), Luxembourg (-0.30 GDP point), Ireland (-0.04 GDP point), Romania (-0.03 GDP point) and Spain (-0.01 GDP point).

With the exception of Finland and Luxembourg, the reduction in R&D intensity is rather modest, even though in some countries, such as Spain, where GDP falls by -3.6% over the 2007-2015 period, the reduction in the level of R&D investments in absolute terms is higher than the reduction of the R&D intensity, close to zero. For Ireland, as previously mentioned, the reduction of the R&D intensity must be carefully interpreted.

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On average, the R&D intensity in the EU countries increases by 0.27 GDP point in the period 2007-2015 with important rises in some member states. The highest increases are found in Slovenia (+0.79 GDP point), Slovakia (+0.73 GDP point), Czech Republic (+0.64 GDP point), Austria (+0.63 GDP point), Belgium (+0.63 GDP point), Bulgaria (+0.52 GDP point) and Denmark (+0.45 GDP point), with increases between 0.45 and 0.79 GDP points. Four of these countries are eastern countries and this confirms the progress accomplished by some lagging countries, such as Slovakia. But once again, these trends must be interpreted with caution.

Table 7.2.11 – Evolution of total R&D intensity in % GDP in EU countries, 2007-2015

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
Finland	3.33%	3.53%	3.73%	3.70%	3.61%	3.40%	3.26%	3.15%	2.88%	-0.45%
Luxembourg	1.61%	1.64%	1.71%	1.51%	1.47%	1.28%	1.31%	1.28%	1.31%	-0.30%
Ireland	1.23%	1.39%	1.61%	1.60%	1.54%	1.56%	1.56%	1.51%	1.19%	-0.04%
Romania	0.52%	0.57%	0.46%	0.45%	0.49%	0.48%	0.39%	0.38%	0.49%	-0.03%
Spain	1.23%	1.32%	1.35%	1.35%	1.32%	1.29%	1.27%	1.23%	1.22%	-0.01%
Sweden	3.25%	3.49%	3.45%	3.22%	3.24%	3.27%	3.30%	3.14%	3.26%	0.01%
Cyprus	0.37%	0.35%	0.38%	0.39%	0.38%	0.37%	0.40%	0.40%	0.38%	0.01%
Croatia	0.79%	0.88%	0.84%	0.74%	0.75%	0.75%	0.82%	0.79%	0.85%	0.06%
Latvia	0.55%	0.58%	0.45%	0.61%	0.70%	0.67%	0.61%	0.69%	0.63%	0.07%
United Kingdom	1.60%	1.60%	1.66%	1.64%	1.65%	1.58%	1.63%	1.65%	1.67%	0.07%
France	2.00%	2.03%	2.18%	2.15%	2.16%	2.20%	2.21%	2.20%	2.20%	0.20%
Italy	1.09%	1.13%	1.18%	1.18%	1.17%	1.23%	1.27%	1.33%	1.29%	0.20%
Malta	0.55%	0.53%	0.52%	0.62%	0.67%	0.83%	0.77%	0.75%	0.77%	0.22%
Lithuania	0.80%	0.79%	0.83%	0.78%	0.90%	0.89%	0.95%	1.03%	1.04%	0.24%
Portugal	1.02%	1.33%	1.44%	1.38%	1.33%	1.26%	1.31%	1.27%	1.26%	0.24%
EU-28	1.75%	1.82%	1.91%	1.91%	1.95%	1.99%	2.01%	2.03%	2.02%	0.27%
The Netherlands	1.69%	1.64%	1.69%	1.72%	1.90%	1.94%	1.95%	2.00%	2.01%	0.33%
Greece	0.57%	0.66%	0.62%	0.59%	0.67%	0.69%	0.80%	0.83%	0.95%	0.38%
Hungary	0.94%	0.96%	1.12%	1.13%	1.18%	1.25%	1.38%	1.34%	1.36%	0.42%
Estonia	1.04%	1.23%	1.37%	1.56%	2.29%	2.10%	1.71%	1.43%	1.47%	0.42%
Germany	2.45%	2.60%	2.73%	2.71%	2.80%	2.87%	2.82%	2.89%	2.87%	0.43%
Poland	0.56%	0.60%	0.66%	0.72%	0.74%	0.88%	0.87%	0.94%	1.00%	0.44%
Denmark	2.50%	2.76%	3.04%	2.90%	2.93%	2.97%	2.96%	2.95%	2.95%	0.45%
Bulgaria	0.43%	0.44%	0.49%	0.56%	0.53%	0.60%	0.63%	0.79%	0.95%	0.52%
Belgium	1.82%	1.91%	1.97%	2.03%	2.14%	2.35%	2.43%	2.46%	2.45%	0.63%
Austria	2.43%	2.58%	2.60%	2.72%	2.67%	2.92%	2.96%	3.04%	3.06%	0.63%
Czech Republic	1.30%	1.24%	1.29%	1.33%	1.55%	1.77%	1.89%	1.96%	1.94%	0.64%
Slovakia	0.45%	0.46%	0.47%	0.61%	0.66%	0.80%	0.82%	0.88%	1.17%	0.73%
Slovenia	1.42%	1.62%	1.82%	2.06%	2.42%	2.58%	2.60%	2.38%	2.21%	0.79%

Source: Eurostat

For example, while Bulgaria has an ambitious Europe 2020 target of 1.5 GDP point for its R&D intensity, its level in 2015 (0.95%) remains well below the EU average (2.02%). In addition, the increase in the R&D intensity of Bulgaria from 2007 (+0.52%), hides a strong decrease of the public intensity that fell from 0.4% of GDP in 2000 to 0.29% in 2007 and 0.25% in 2015, the lowest value in EU-28. The increase in the private intensity, from 0.13% in 2007 (0.11% in 2000) to 0.70% in 2015, is itself mostly due to investments by foreign pharmaceutical companies for clinical trials, which are therefore not reflected by a similar increase in the R&D personnel or in research infrastructures. These foreign investments notably explain most of the rise that occurred from 2007 onward.

7.2.3.2 The evolution at sectorial level and by socioeconomic objective

Private R&D investments

To begin with private R&D investments, it was necessary to disaggregate all the data to adhere to the NEMESIS model nomenclature (30 sectors including the public sector, see tables 7.2.12 and 7.2.13).

The data on private R&D investments are available in EUROSTAT in NACE rev2 (level 2), but, as shown in Table 7.2.14, many of the data were missing on a detailed sectorial level for the period 2007 to 2015. There is in fact no sectorial detail for 2015, while for the period 2007-2014 31% of the data were missing.

The quality of the data is highly variable, depending on the country. At one end of the spectrum, no data is missing for the Czech Republic, Cyprus or Slovenia, while, at the other end, as much as 81% of the data are missing for Luxembourg, 75% for Sweden and 73% for Greece.

However, data were available at a more aggregated level, which allowed for adequate estimations of the missing data through simple interpolation, extrapolation and disaggregation techniques.

The results are shown, after re-aggregation at EU-28 level, in table 7.2.15.

The table shows that the increase of 0.18 GDP point in the private R&D intensity at EU-28 level over the period 2007-2015, is caused for about 0.073 GDP point (41%) by investments made in the transport equipment sectors, for 0.024 GDP point (13%) by the investments in the communications sector and for 0.016 GDP point (9%) by those in the distribution sector, these three sectors accounting for about two thirds overall of the rise in the private R&D intensity over the period.

The other noticeable increase concerns the market services sector (+0.044 GDP point), which includes the KIBS (Knowledge Intensive Business Services) and notably the market research services.

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Table 7.2.12 – Correspondence between NEMESIS sectors and the NACE rev. 2 (1/2)

NEMESIS	NACE Rev.2
1 Agriculture	
	A01 Crop and animal production, hunting and related service activities
	A02 Forestry and logging
	A03 Fishing and aquaculture
2 Coal and Coke	
	B05 Mining of coal and lignite
	B07 Mining of metal ores
	B08 Other mining and quarrying
	B9.9 Support activities for other mining and quarrying
3 Oil & Gas Extraction	
	B06 Extraction of crude petroleum and natural gas
	B9.1 Support activities for petroleum and natural gas extraction
4 Gas Distribution	
	D35.2 Manufacture of gas; distribution of gaseous fuels through mains
	D35.3 Steam and air conditioning supply
5 Refined Oil	
	C19 Manufacture of coke and refined petroleum products
6 Electricity	
	D35.1 Electric power generation, transmission and distribution
7 Water Supply	
	E36 Water collection, treatment and supply
8 Ferr & non Ferrous Metals	
	C24 Manufacture of basic metals
9 Non Metallic Min Products	
	C23 Manufacture of other non-metallic mineral products
10 Chemicals	
	C20 Manufacture of chemicals and chemical products
	C21 Manufacture of basic pharmaceutical products and pharmaceutical preparations
11 Metal Products	
	C25 Manufacture of fabricated metal products, except machinery and equipment
12 Agr & Indus Machines	
	C28 Manufacture of machinery and equipment n.e.c.
13 Office machines	
	C26 Manufacture of computer, electronic and optical products
14 Electrical Goods	
	C27 Manufacture of electrical equipment
15 transport Equipment	
	C29 Manufacture of motor vehicles, trailers and semi-trailers
	C30 Manufacture of other transport equipment
16 Food. Drink & Tobacco	
	C10-C12 Manufacture of food products; beverages and tobacco products
17 Tex.. Cloth & Footw.	
	C13-C15 Manufacture of textiles, wearing apparel, leather and related products
18 Paper & Printing Products	
	C17 Manufacture of paper and paper products
	C18 Printing and reproduction of recorded media
19 Rubber & Plastic	
	C22 Manufacture of rubber and plastic products
20 Other Manufactures	
	C16 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	C31 C32 Manufacture of furniture; other manufacturing
	C33 Repair and installation of machinery and equipment
	E37-E39 Sewerage, waste management, remediation activities

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Table 7.2.13 – Correspondence between NEMESIS sectors and the NACE rev. 2 (2/2)

NEMESIS	NACE Rev.2
21 Construction	F Construction
22 Distribution	G45 Wholesale and retail trade and repair of motor vehicles and motorcycles G46 Wholesale trade, except of motor vehicles and motorcycles G47 Retail trade, except of motor vehicles and motorcycles
23 Lodging & Catering	I Accommodation and food service activities
24 Inland Transports	H49 Land transport and transport via pipelines
25 Sea & Air Transport	H50 Water transport H51 Air transport
26 Other Transports	H52 Warehousing and support activities for transportation
27 Communication	H53 Postal and courier activities J58 Publishing activities J59_J60 Motion picture, video, television programme production; programming and broadcasting activities J61 Telecommunications
28 Bank. Fin., Ins. & Real Est.	K64 Financial service activities, except insurance and pension funding K65 Insurance, reinsurance and pension funding, except compulsory social security K66 Activities auxiliary to financial services and insurance activities L Real estate activities N77 Rental and leasing activities
29 Other Market Services	J62_J63 Computer programming, consultancy, and information service activities M69_M70 Legal and accounting activities; activities of head offices; management consultancy activities M71 Architectural and engineering activities; technical testing and analysis M72 Scientific research and development M73 Advertising and market research M74_M75 Other professional, scientific and technical activities; veterinary activities N78 Employment activities N79 Travel agency, tour operator reservation service and related activities N80-N82 Security and investigation, service and landscape, office administrative and support activities S95 Repair of computers and personal and household goods S96 Other personal service activities
30 Non Market Services	O Public administration and defence; compulsory social security P Education Q86 Human health activities Q87_Q88 Residential care activities and social work activities without accommodation R90-R92 Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities R93 Sports activities and amusement and recreation activities S94 Activities of membership organisations

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Table 7.2.14 – Percentage of missing data for Business Enterprises R&D (BERD) in NACE rev.-2, period 2007-2014

	Observations missing	Years missing	Ratio
Belgium	133	2014	28%
Bulgaria	135		28%
Czech Republic	0		0%
Denmark	117	2008	24%
Germany	78		16%
Estonia	100		21%
Ireland	300	2008, 2014	63%
Greece	348	2008, 2009, 2010, 2012, 2014	73%
Spain	26		5%
France	107	2014	22%
Croatia	43		9%
Italie	49		10%
Cyprus	0		0%
Latvia	345	2009, 2011	72%
Lithuania	155		32%
Luxembourg	389	2008, 2010, 2012 ,2014	81%
Hungary	118		25%
Malta	25		5%
Netherlands	179		37%
Poland	163		34%
Portugal	89		19%
Romania	210		44%
Slovenia	0		0%
Slovakia	226		47%
Finland	215		45%
Sweden	359		75%
United Kingdom	45		9%
EU-28	3954		31%

Source: Authors calculations from EUROSTAT

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Table 7.2.15 – Evolution of Business Enterprises R&D (BERD) at sectorial level between 2007 and 2015 (in % GDP)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
01 Agriculture	0.004%	0.004%	0.004%	0.004%	0.005%	0.004%	0.005%	0.005%	0.005%	0.001%
02 Coal and Coke	0.003%	0.003%	0.003%	0.003%	0.003%	0.003%	0.003%	0.003%	0.003%	0.001%
03 Oil & Gas Extraction	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
04 Gas Distribution	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
05 Refined Oil	0.003%	0.003%	0.003%	0.002%	0.004%	0.005%	0.004%	0.004%	0.004%	0.001%
06 Electricity	0.007%	0.008%	0.009%	0.008%	0.008%	0.009%	0.009%	0.009%	0.009%	0.002%
07 Water Supply	0.001%	0.001%	0.002%	0.002%	0.002%	0.001%	0.002%	0.002%	0.001%	0.000%
08 Ferrous & non Ferrous Metals	0.012%	0.013%	0.014%	0.012%	0.014%	0.013%	0.014%	0.014%	0.014%	0.002%
09 Non Metallic Min Products	0.008%	0.009%	0.009%	0.009%	0.009%	0.009%	0.009%	0.009%	0.008%	0.000%
10 Chemicals	0.139%	0.142%	0.146%	0.140%	0.141%	0.145%	0.143%	0.141%	0.139%	0.000%
11 Metal Products	0.028%	0.030%	0.036%	0.035%	0.033%	0.035%	0.036%	0.034%	0.035%	0.007%
12 Agricultural & Industrial Machines	0.110%	0.109%	0.090%	0.090%	0.095%	0.100%	0.102%	0.103%	0.101%	-0.008%
13 Office machines	0.108%	0.105%	0.104%	0.100%	0.105%	0.110%	0.111%	0.110%	0.108%	0.001%
14 Electrical Goods	0.042%	0.043%	0.046%	0.043%	0.043%	0.045%	0.046%	0.045%	0.044%	0.002%
15 Transport Equipment	0.201%	0.220%	0.225%	0.235%	0.250%	0.262%	0.258%	0.274%	0.274%	0.073%
16 Food, Drink & Tobacco	0.016%	0.016%	0.017%	0.017%	0.017%	0.018%	0.018%	0.018%	0.018%	0.002%
17 Textile, Clothes & Footwear.	0.006%	0.007%	0.007%	0.007%	0.007%	0.007%	0.008%	0.008%	0.008%	0.001%
18 Paper & Printing Products	0.007%	0.008%	0.009%	0.009%	0.006%	0.006%	0.006%	0.006%	0.006%	-0.001%
19 Rubber & Plastic	0.019%	0.019%	0.019%	0.019%	0.020%	0.021%	0.021%	0.021%	0.021%	0.002%
20 Other Manufactures	0.029%	0.030%	0.037%	0.033%	0.035%	0.035%	0.037%	0.037%	0.037%	0.008%
21 Construction	0.005%	0.005%	0.007%	0.007%	0.006%	0.006%	0.006%	0.007%	0.007%	0.002%
22 Distribution	0.032%	0.033%	0.036%	0.042%	0.047%	0.049%	0.048%	0.048%	0.048%	0.016%
23 Lodging & Catering	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
24 Inland Transports	0.001%	0.001%	0.001%	0.001%	0.001%	0.001%	0.001%	0.001%	0.001%	0.000%
25 Sea & Air Transport	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
26 Other Transport	0.001%	0.001%	0.002%	0.001%	0.002%	0.002%	0.001%	0.001%	0.001%	0.000%
27 Communication	0.105%	0.109%	0.115%	0.117%	0.121%	0.123%	0.128%	0.129%	0.129%	0.024%
28 Bank, Finance, Insurance, Real Estate	0.026%	0.025%	0.025%	0.024%	0.024%	0.025%	0.025%	0.025%	0.025%	-0.001%
29 Other Market Services	0.214%	0.220%	0.230%	0.235%	0.251%	0.249%	0.250%	0.254%	0.257%	0.044%
Sum	1.127%	1.165%	1.196%	1.196%	1.250%	1.282%	1.291%	1.309%	1.304%	0.177%

Source: Author's calculations from EUROSTAT

Public R&D investments Concerning public R&D, it was necessary to assess how these investments will benefit the different economic sectors the NEMESIS model distinguishes. The main problem is that only limited information is available on the field of application of these investments. The only reliable information is provided by the Government Budget Appropriations or Outlays on Research and Development (GBAORD) data, which does not exactly correspond to the Frascati definitions for Public R&D investments.

The GBOARD data, that are available at EU 28 level for the period 2007-2015, disaggregate public R&D into application fields or socioeconomic objectives, as displayed in table 7.2.16. Based on the GBOARD data, the 0.09 GDP point increase in public R&D investments over 2007-2015, was associated for 0.128 GDP point with civil objectives (Total civil R&D appropriations). The difference of -0.039 GDP point is attributable to the fall in the R&D investments for Defense.

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Table 7.2.16 – Evolution of public R&D investments by socio-economic objective between 2007 and 2015 (in % GDP)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
Exploration and exploitation of the earth	0.008%	0.011%	0.012%	0.013%	0.013%	0.014%	0.014%	0.015%	0.015%	0.008%
Environment	0.016%	0.018%	0.020%	0.019%	0.018%	0.019%	0.018%	0.018%	0.019%	0.003%
Exploration and exploitation of space	0.028%	0.028%	0.036%	0.036%	0.041%	0.036%	0.038%	0.037%	0.036%	0.007%
Transport, telecommunication and other infrastructures	0.014%	0.024%	0.027%	0.025%	0.021%	0.022%	0.022%	0.021%	0.021%	0.007%
Energy	0.020%	0.024%	0.026%	0.028%	0.028%	0.028%	0.031%	0.030%	0.029%	0.010%
Industrial production and technology	0.083%	0.061%	0.069%	0.070%	0.071%	0.065%	0.066%	0.063%	0.062%	-0.001%
Health	0.052%	0.052%	0.057%	0.059%	0.060%	0.061%	0.065%	0.065%	0.064%	0.012%
Agriculture	0.022%	0.024%	0.024%	0.024%	0.025%	0.024%	0.024%	0.023%	0.023%	0.001%
Education	0.005%	0.007%	0.007%	0.007%	0.007%	0.008%	0.009%	0.010%	0.010%	0.005%
Culture, recreation, religion and mass media	0.006%	0.008%	0.008%	0.009%	0.008%	0.009%	0.008%	0.007%	0.007%	0.001%
Political and social systems, structures and processes	0.012%	0.020%	0.021%	0.025%	0.023%	0.023%	0.020%	0.021%	0.020%	0.008%
General advancement of knowledge: General University Funds (GUF)	0.208%	0.203%	0.226%	0.227%	0.234%	0.243%	0.249%	0.250%	0.247%	0.039%
General advancement of knowledge: Other sources than GUF	0.097%	0.118%	0.126%	0.124%	0.125%	0.127%	0.126%	0.130%	0.127%	0.030%
Defence	0.073%	0.060%	0.060%	0.048%	0.034%	0.037%	0.033%	0.035%	0.034%	-0.039%
Total civil R&D appropriations	0.562%	0.596%	0.659%	0.667%	0.674%	0.678%	0.690%	0.689%	0.681%	0.128%
Total R&D appropriations	0.625%	0.658%	0.719%	0.719%	0.708%	0.715%	0.723%	0.723%	0.715%	0.090%

Source: Authors calculations from EUROSTAT (GBOARD)

Concerning civil appropriations or outlays, R&D investments are classified according to 12 socio-economic objectives. While some objectives are general as “General advancement of knowledge”, other are more “content-” or sector-related, such as Energy or Agriculture. However, the links between these socio-economic objectives and the economic sectors that may benefit from these investments can only be identified indirectly, by means of hypotheses relying on the amount of investments in similar sectors. These hypotheses have been used in the NEMESIS model to estimate the knowledge R&D spill-overs from public research towards the private sector, in a very tentative way .

The hypotheses linking public investment in R&D and the economic sector of NEMESIS are displayed in table 7.2.17.

When the socioeconomic objectives are very general, such as “General Advancement of Knowledge”, the NEMESIS link follows the grand-fathering principle and all the sectors receive spillovers from public research, proportionally to their relative R&D effort in percentage of total R&D investment. When the socioeconomic objectives are more specific, the link was made through related sectors.

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Table 7.2.17 – Link between Public R&D investments and NEMESIS sectors

Socio-economic objectives	NEMESIS Sectors
Exploration and exploitation of the earth	All grand-fathering
Environment	All grand-fathering
Exploration and exploitation of space	All grand-fathering
Transport, telecommunication and other infrastructures	Construction, Transport services, Water supply, Telecoms (21, 24, 25, 26, 27, 07)
Energy	Energy, Non metal. Min. products, Chemicals, Office machines, Elec. Goods, Trans. Equip. (04, 05, 06, 09, 10, 13, 14, 15)
Industrial production and technology	All Ind. Sectors (8 to 20)
Health	Other market serv. (29)
Agriculture	Agriculture (01)
Education	Other market serv. (29)
Culture, recreation, religion and mass media	Other market serv. (29)
Political and social systems, structures and processes	Other market serv. (29)
General advancement of knowledge: General University Funds (GUF)	All grand-fathering
General advancement of knowledge: Other sources than GUF	All grand-fathering
Defence	All Ind. Sectors and Other market serv. (8 to 20 & 29)

7.2.3.3 Other methodological issues

Before presenting how these evolutions in public and private R&D investments have impacted the relative economic performance of the EU Member States, we address here two additional methodological issues:

- Firstly, the results of the simulations made using NEMESIS are presented in comparison to a reference scenario that is a projection of the future European economy, as described briefly below this reference scenario;
- Secondly we summarize the R&D and innovation mechanisms underpinning the NEMESIS model, that are necessary to interpret the simulation results.

The reference scenario

The reference scenario is based on the extrapolation of past trends and different forecasts at medium and long term carried out by the DG ECFIN and notably the DG ECFIN Ageing Report. The overall dynamic of this scenario can be split into two phases (table 7.2.18). In the medium term, up to 2020-2025, the European period of crisis ends. After that, in the long run, the decline of the labor force, combined with a moderated labor productivity growth, leads to a lower long term growth path than just after the crisis.

Table 7.2.18 – Evolution of GDP in the reference scenario

	<i>Intensity of innovation assets in % GDP</i>					
	2007	2014	2020	2025	2030	2050
Private R&D expenditures	1.1%	1.3%	1.3%	1.3%	1.3%	1.2%
Public R&D expenditures	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
ICT investments	1.2%	1.1%	1.1%	1.1%	1.1%	1.0%
Other Intangible investments (Software and Formation)	2.4%	2.3%	2.3%	2.3%	2.2%	2.2%
Total investment in innovation assets	5.3%	5.4%	5.4%	5.4%	5.3%	5.2%

Source: NEMESIS model reference scenario

The period between 2015 and 2025 is characterized by the revival of internal demand and the main contributors to GDP are private consumption and gross fixed capital formation. After 2025, the trade balance is negatively impacted by the deterioration of competitiveness with an increase in real wages

higher than the rise of labor productivity. This is mainly due to the reduction in unemployment and to the influence of the labor supply shortage on the long-term growth potential.

Finally, in the reference scenario, the intensities of innovation assets are kept constant at sectorial level from 2014 to 2050 (table 7.2.19). They decrease slightly at macro-EU level with the evolution of the sectorial composition of the economy and the increasing contribution of service industries to EU GDP up to 2050. They nevertheless remain roughly stable with a global intensity in innovation assets passing from 5.4% of EU GDP in 2014 to 5.2% in 2050.

Table 7.2.19 – Evolution of innovation assets in the reference scenario

	<i>Intensity of innovation assets in % GDP</i>					
	2007	2014	2020	2025	2030	2050
Private R&D expenditures	1.1%	1.3%	1.3%	1.3%	1.3%	1.2%
Public R&D expenditures	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
ICT investments	1.2%	1.1%	1.1%	1.1%	1.1%	1.0%
Other Intangibles investments (Softwares	2.4%	2.3%	2.3%	2.3%	2.2%	2.2%
Total investments in innovation assets	5.3%	5.4%	5.4%	5.4%	5.3%	5.2%

Source: The NEMESIS model

Important NEMESIS R&I mechanisms for the simulation For the simulation, in the model we will increase the R&D intensity to reproduce the increase observed over the period 2007-2015. The first consequence, as described in figure 7.2.3, will be to increase the knowledge of the different economic sectors in the different EU countries.

The R&D investments of private firms will diffuse knowledge from the knowledge transfer matrices (in black) at inter-sectorial and international levels simultaneously. Public R&D will increase the R&D used by the different sectors, following the rules described in the preceding section, and will also diffuse knowledge through the same matrices as private R&D.

The rise of R&D will also have pulling effects on the other innovation inputs (Cf. figure 7.2.4), that will increase and that will also provoke an increase in their respective knowledge stocks.

Figure 7.2.3 – The impact of a rise of R&D on knowledge

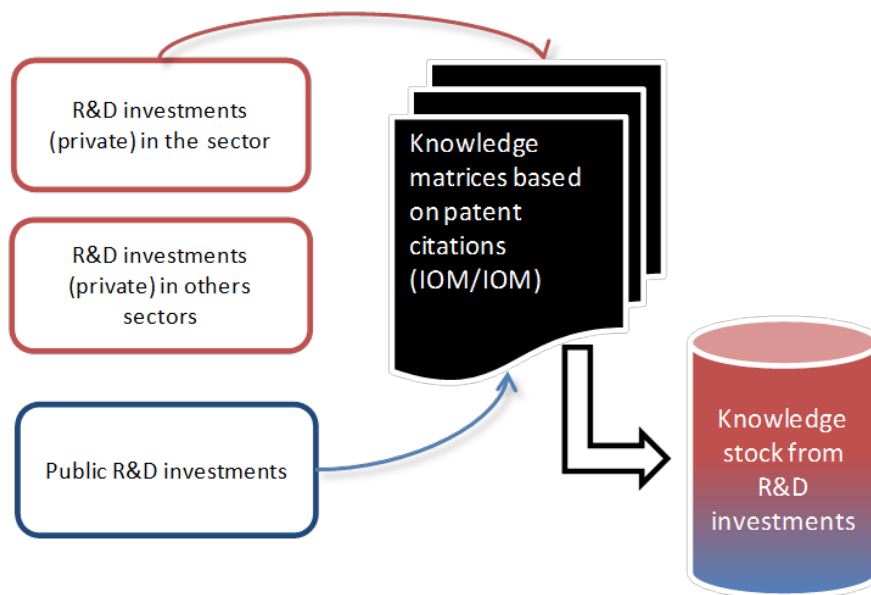


Figure 7.2.4 – The repercussion on other innovation inputs

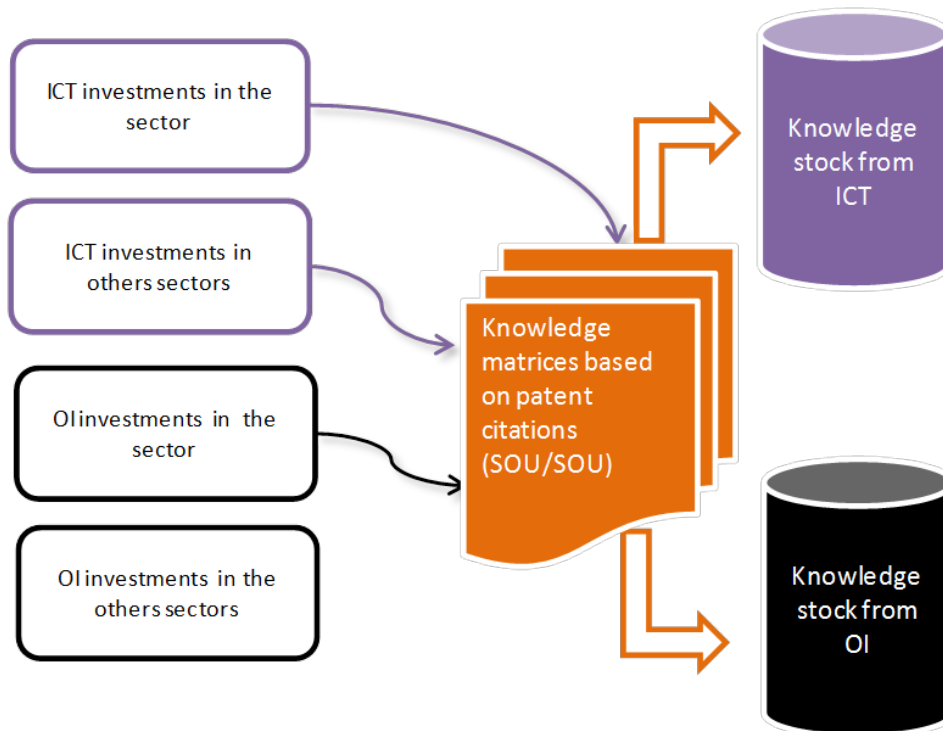
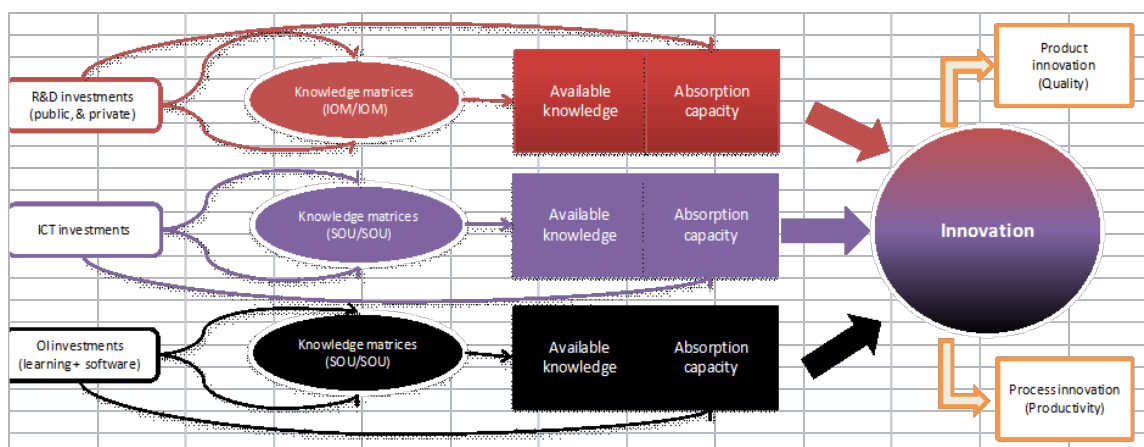


Figure 7.2.5 – The impact on economic performance



The creation of new knowledge will progressively translate into product and process innovations (Cf. figure 7.2.5) that will affect economic activity and employment. We will call this first impact pathway the “*Knowledge spillovers effect*”.

The second impact pathway will come from the increase in the R&D intensity and possibly from the increase in the intensity of the other innovation inputs, and from pulling effects. It will increase the ability of sectors to transform existing knowledge into new product and process innovations, that will also affect economic activity and employment. We call this second impact pathway the “*Intensity effect*”.

As different countries have different characteristics as well as contrasted evolutions in their R&D intensity over the period 2007-2015, the impacts in the different countries will be very diverse. The relative competitiveness of the different sectors and countries will be modified and there will be, in addition to knowledge spillovers, rent (or productivity) spillovers conveyed through the exchange of goods and services between them, that will globally increase the positive impacts of innovations. Also, the pulling effect that one innovation asset has on the two others will provoke changes in all innovation input intensities and externalities simultaneously, increasing the positive impacts. But negative indirect impacts will also occur. They will mainly come from the fall in the demand for production inputs provoked by the rise of TFP, that will reduce activity, and from possible tensions on the labor market.

7.2.3.4 The results at EU macro level

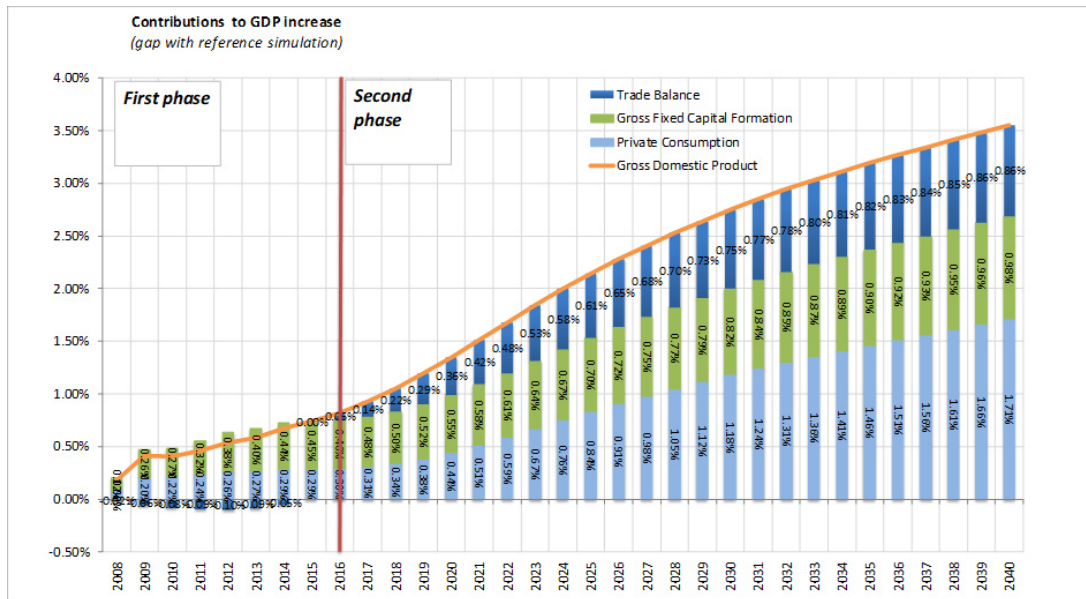
We begin this section by analyzing the results of the simulation at the EU macro level, and in the two next sub-sections will present the main evolutions at sectorial and national levels respectively.

The results for EU GDP Concerning GDP, the impacts follow two main phases as illustrated by the figure 7.2.6:

1. During the first phase, up to 2015, there are few innovations and supply side effects. The main impacts on GDP come from the demand induced by the investments in R&D that grow by +0.27 GDP point between 2007 and 2015, compared to their level in the reference scenario of the model. The investments in R&D push the internal demand up, but this increase in demand determines inflationary pressures, deteriorating the external balance of the EU. GDP gains remain nevertheless positive, with + 0.74% in 2015, with however one third of these gains (0.27 GDP point) resulting from the capitalization of the rise of R&D investment in GDP, following the new accounting rules introduced by EUROSTAT in 2014, with the transition from SEA 95 to SEA 2010.
2. During the second phase, beginning in 2016, GDP gains gradually grow with the appearance of innovations on the market. All the components of GDP contribute positively to GDP gains, with an increasing contribution of external trade up to 2030. GDP gains reach 2.75% in 2030 and 3.55% in 2040.

For the year 2030, the origin of GDP gains (2.75%) can be split up as follows: 1.2 point from the rise of final consumption, 0.8 point from the rise of total investment and 0.75, point from the external balance surplus.

Figure 7.2.6 – The impact on EU GDP (in % difference from the reference scenario)



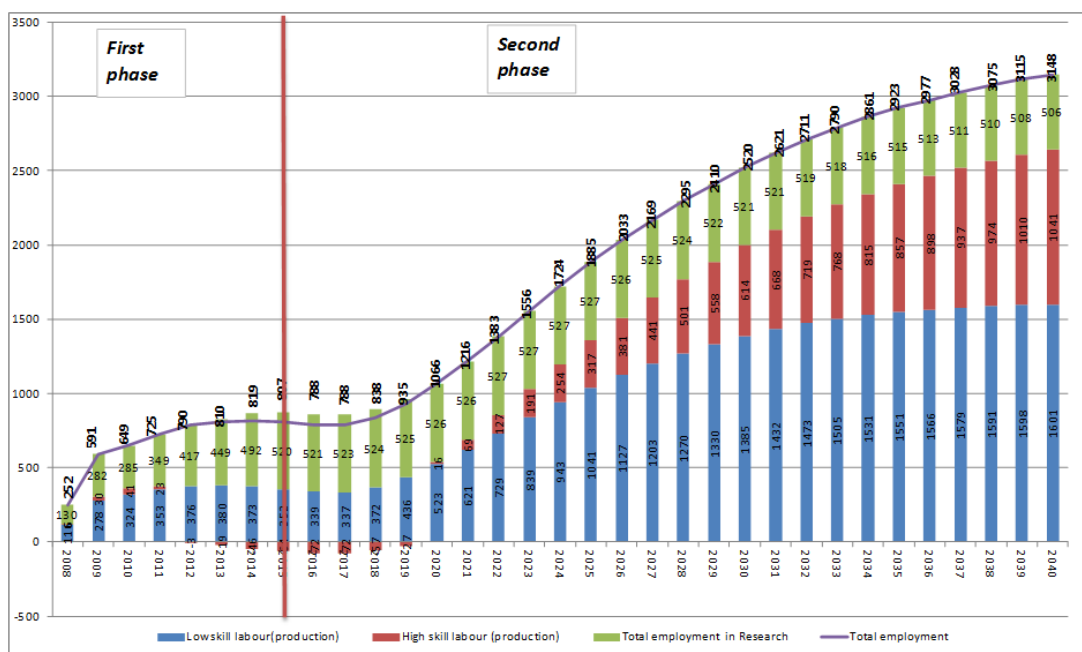
Source: The NEMESIS model

The impacts on employment at EU level The impacts on employment at EU level should also be analyzed in two phases (see figure 7.2.7):

1. During the investment phase, up to 2015, job creation mainly occurs in research organizations and is made possible by the increase in research investments in the public and private sectors. In 2015, the rise in research intensity (+0.27 GDP point, compared to its level in 2007), increases employment by 511000 units in full time equivalent, compared to its level in the reference scenario. Total employment creation rises by 788000, with 277000 additional jobs created in production activities, as a result of the better macro-economic context that evolves. In fact, these 277000 new jobs are the net balance between 352000 new low skilled jobs and a reduction (-64000) of the number of high skilled jobs in production activities. The reason of this reduction in high skilled labor in production is that the rise of employment in research, which concerns high skilled personnel, crowds-out high skilled labor in production.
2. During the second phase, beginning in 2016, the level of employment in research stabilizes as research intensity no longer rises. High skilled employment in production re-increases progressively. In 2030, the level of employment is 2.52 million higher than in the reference scenario, of which 512000 are new jobs in the research sector and 614000 are high skilled jobs in production.

More than 50% of the total jobs created are low skilled jobs in production (an increase of 1.385 million). After 2030, the pressure on wages contributes to a progressive decrease in the number of additional job creations. In 2040 the total jobs created reaches 3.148 million of which 506,000 are in research, 1.041 million are high skilled positions in production and 1.601 million are low skilled jobs.

Figure 7.2.7 – The impact on total employment in EU (difference from reference scenario in thousands)



Source: The NEMESIS model

7.2.3.5 The results at EU sectorial level

This section analyzes now the evolutions on a detailed sectorial level.

Sectorial Value Added Concerning the sectorial value added, different phases of impacts can also be observed (table 7.2.20):

1. During the first years of the investment phase up to 2011-2012, the value-added creation occurs mainly in the service sectors and in all sectors producing consumer goods. The reason is in the hiring of new research personnel, that increases wages and consumption, and then pulls up the production of the goods and services that compose the final consumption of households. The industrial sectors, that are also R&D intensive, see their competitiveness deteriorate on the

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external market, as they increase their research investments and therefore their production costs, without sufficient process innovations to alleviate their costs and sufficient product innovations to increase their non-price competitiveness. For example, in 2012, value added decreases by -0.4% in chemicals and by -0.1% in high tech industries, while it increases by +0.4% in distribution and by +0.3% in other market services.

2. Then, after 2011-2012, the value-added in R&D industrial sectors grows faster than in the other sectors of the economy, which are less R&D intensive and less exposed to international competition. In 2030 value added increases by 5.3% in chemicals and 6.3% in high tech industries, while the increase is limited to 2.3% in distribution and to 2.7% in other market services.

Table 7.2.20 – The impacts of EU-28 sectorial value-added (in % deviation from the reference scenario)

	2008	2009	2010	2011	2012	2013	2014	2015	2020	2030
- Agriculture	0.1%	0.3%	0.3%	0.3%	0.4%	0.4%	0.5%	0.5%	1.0%	2.5%
- Utilities	0.0%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.4%	1.7%
- Heavy Industries	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	1.0%	2.8%
- Chemicals	-0.1%	-0.2%	-0.3%	-0.4%	-0.4%	-0.3%	0.1%	0.6%	2.8%	5.3%
- High Tech Industries	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	0.1%	0.6%	1.1%	3.5%	6.3%
- Transport Equipments	-0.1%	-0.1%	-0.1%	0.0%	0.2%	0.6%	1.5%	2.6%	7.9%	12.3%
- Other Industries	0.2%	0.3%	0.3%	0.2%	0.3%	0.3%	0.4%	0.5%	1.3%	3.1%
- Construction	0.2%	0.4%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.8%	1.9%
- Distribution	0.1%	0.3%	0.3%	0.3%	0.4%	0.4%	0.4%	0.4%	0.8%	2.3%
- Transport	0.1%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.4%	1.3%	3.4%
- Communication	0.1%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.8%	2.3%
- Bank, finance, insurance	0.1%	0.3%	0.3%	0.4%	0.4%	0.4%	0.5%	0.5%	0.8%	2.1%
- Other market services	0.1%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.5%	1.1%	2.7%

Source: The NEMESIS model

Sectorial employment Concerning employment, the results at sectorial level are much more contrasted than for value-added (see table 7.2.21):

1. During the first years, employment creation is concentrated in the R&D intensive sectors. For example, of the 252,000 jobs created in 2008, 5,000 are in chemicals, 15,000 are in high tech industries, 10,000 in transport equipment, 14,000 in other industries, 60,000 in other market services and 80,000 in non-market industries (which includes the public research sector in NEMESIS). About two thirds of employment creation therefore occurs in the sectors with R&D investments.
2. Then the creation of jobs spread more widely between sectors that are pulled up by the increase in internal and external demand. Employment increases in almost every sector until 2012, but

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afterwards there are decreases in some R&D intensive sectors, such as chemicals, high tech industries and transport equipment, where process innovations are important and tend to do away with jobs. In other sectors, such as heavy industry that produces intermediate goods, job destruction originates from productivity improvements in the other sectors of the economy, which reduces their consumption of intermediate products.

3. In the long term (2030), while most of the new jobs that are created are in the services sector - which currently accounts for about 70% of total employment against only 15% for industry, about 30% of total job creation nevertheless occurs in the industrial sector: 799,000 out of 2.52 million. The reason is that the rise of the R&D intensity significantly improves the external competitiveness of the industrial sectors and prevents job destruction in industry, due to the competition from non-EU countries.

Table 7.2.21 – The impacts on EU-28 sectoral employment (in thousands and in difference from the reference scenario)

	2008	2009	2010	2011	2012	2013	2014	2015	2020	2030
- Agriculture	3	6	7	8	8	8	8	8	17	46
- Utilities	2	4	4	5	6	6	6	6	8	23
- Heavy Industries	4	8	7	6	4	1	-2	-8	5	88
- Chemicals	5	7	6	9	11	10	9	6	9	21
- High Tech Industries	15	26	24	31	36	32	30	22	45	119
- Transport Equipments	10	18	17	22	27	24	21	12	-6	12
- Other Industries	14	31	32	33	35	35	35	34	81	245
- Construction	16	45	58	67	74	78	79	79	102	270
- Distribution	29	73	89	99	105	107	105	101	159	465
- Transport	5	12	12	10	8	6	2	-1	7	63
- Communication	3	7	9	10	11	11	11	11	10	18
- Bank, finance, insurance	8	24	32	35	38	40	40	41	68	228
- Other market services	60	139	164	207	234	244	264	264	322	675
- Non-market services	80	192	189	182	194	208	212	233	240	247
- Total	252	591	649	725	790	810	819	807	1066	2520

Source: The NEMESIS model

The impacts on trade balance Concerning trade balance, the table 7.2.22 shows a similar evolution with impacts in two phases that are identified with reference to the analysis at sectorial level:

1. During the investment phase up to 2015, the external competitiveness of the EU deteriorates as few innovations appear and a direct increase of imports occurs, as a result of the rise in household final consumption and investment, whereas the increase of R&D investment induces inflationary

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pressures. The external balance stays negative until 2014, with a maximum deficit of the trade balance of 13.1 billion euros in 2012.

2. Then, in the longer term, the appearance of innovation improves the external competitiveness of EU firms with exports increasing gradually in time. In 2030, the trade balance surplus reaches 131 billion euros. About two thirds of these gains occur in the industrial sectors, which are more R&D intensive and more open to international competition.

Table 7.2.22 – The impact on EU-28 sectorial trade balance (in billion € of 2005 and in difference from the reference scenario)

	2008	2009	2010	2011	2012	2013	2014	2015	2020	2030
- Agriculture	-26	-83	-130	-176	-210	-214	-182	903	460	1411
- Utilities	-120	-342	-465	-561	-629	-654	-598	1630	809	2587
- Heavy Industries	-97	-294	-457	-583	-672	-649	-502	4687	2553	7020
- Chemicals	-326	-897	-1235	-1544	-1731	-1615	-1006	11609	6849	16669
- High Technological Industries	-720	-1968	-2676	-3260	-3610	-3236	-1966	22952	13936	30895
- Transports Equipment	-310	-834	-1034	-1154	-1135	-682	290	17216	11339	22456
- Other Industries	-301	-921	-1370	-1732	-1963	-1940	-1646	7961	4233	11792
- Construction	-37	-114	-172	-220	-261	-280	-279	129	11	216
- Distribution	-62	-199	-308	-388	-425	-412	-332	2859	1452	4521
- Transport	-113	-372	-572	-726	-777	-715	-488	8066	3966	13216
- Communication	-40	-124	-183	-235	-277	-299	-306	-27	-81	-44
- Bank, finance, insurance	-41	-175	-234	-238	-89	133	391	5264	3218	7276
- Other market services	-171	-550	-825	-1025	-1014	-856	-540	7979	4396	12018
- All sectors	-2415	-7026	-9875	-12104	-13072	-11696	-7410	91976	53526	131096

Source: The NEMESIS model

7.2.3.6 The results at national level

Finally this section details the results for the Member States, underlying the strong impact that external trade has on the overall economic impact.

Impact of GDP The first statement, illustrated in table 7.2.23 and figure 7.2.8, is that the impacts on GDP in the different countries are in line with the evolution of their R&D intensity during the period 2007-2015. These impacts range, in 2030, from 0% in Spain, that more or less maintains its R&D intensity constant in 2015 as compared to 2007, up to 18.5% in Slovenia, which increases its R&D intensity by 0.79 GDP point, the best performance across EU-28.

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Table 7.2.23 – Long term impacts on GDP per country (in % diff. from the reference scenario)

Evolution of GDP	GDP gain in 2030 in %	Increase in long term annual growth rate of GDP (2030-2050)	Increase in R&D intensity
Austria	7.25%	0.14%	0.63%
Belgium	5.91%	0.19%	0.63%
Bulgaria	1.88%	0.24%	0.52%
Cyprus	1.11%	0.06%	0.01%
Czech Republic	4.70%	0.10%	0.64%
Germany	3.33%	0.04%	0.43%
Denmark	4.09%	0.08%	0.45%
Estonia	6.99%	0.15%	0.42%
Spain	-0.03%	-0.03%	-0.01%
Finland	1.28%	-0.12%	-0.45%
France	1.83%	0.10%	0.20%
Greece	5.03%	0.38%	0.38%
Hungary	4.58%	0.19%	0.42%
Ireland	5.17%	0.10%	-0.04%
Italy	2.27%	0.10%	0.20%
Lithuania	2.32%	0.06%	0.24%
Luxembourg	0.68%	-0.46%	-0.30%
Latvia	0.80%	-0.01%	0.07%
Malta	2.88%	0.02%	0.22%
The Netherlands	2.07%	0.10%	0.33%
Poland	6.27%	0.13%	0.44%
Portugal	2.55%	0.02%	0.24%
Romania	0.45%	0.08%	-0.03%
Sweden	0.95%	-0.04%	0.01%
Slovenia	18.51%	0.50%	0.79%
Slovakia	5.20%	0.11%	0.73%
The United-Kingdom	1.91%	0.09%	0.07%
EU-28	2.75%	0.07%	0.27%

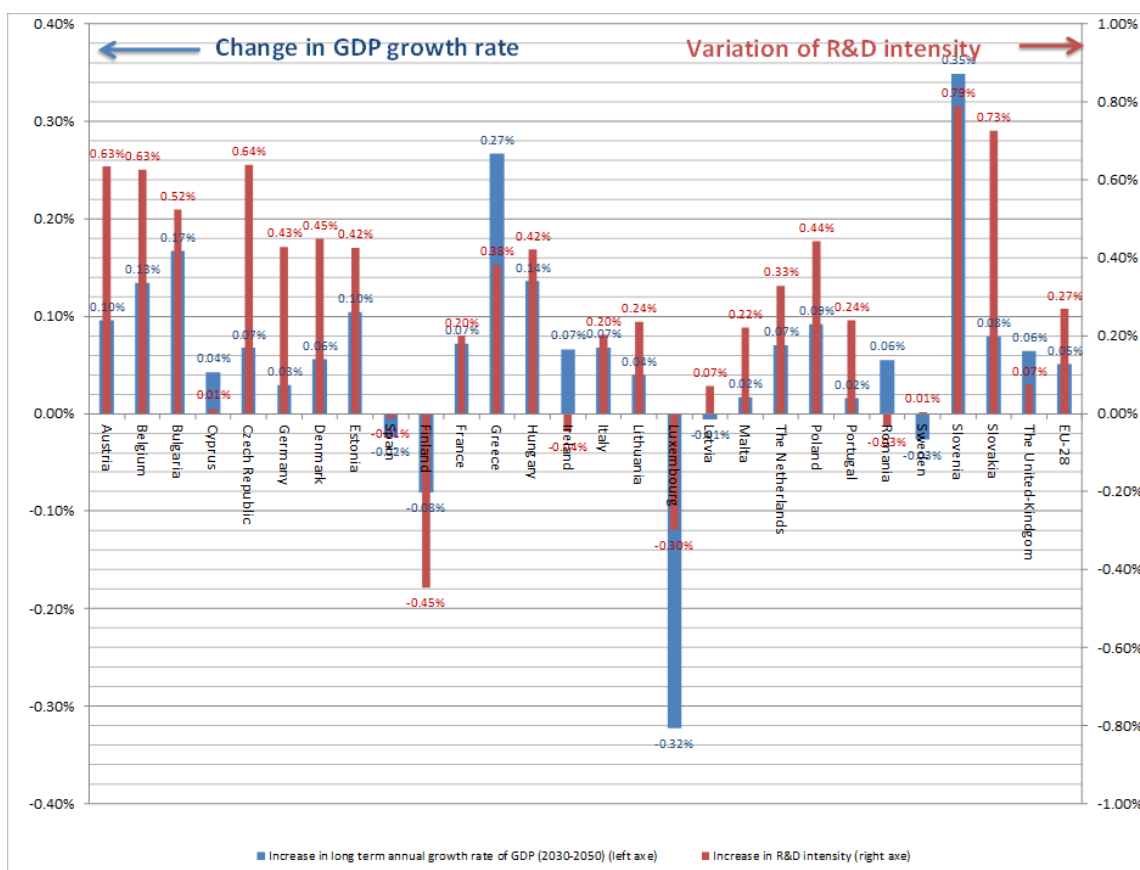
Source: The NEMESIS model

To focus more closely on this, Slovenia, after five years of economic crisis, is expected to experience a steady acceleration of GDP with 2.3% growth in 2015, followed by 2.5% in 2016, and then 3% expected for 2017-2018. This is a remarkable performance, as, during the same period, Slovenia underwent a strong deleveraging policy, in order to reduce its public debt that exceeded 80% of GDP. An attractive feature of the Slovenian economy is furthermore the development of its industry, that

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yields about one quarter of its GDP, with, from 1980, an evolution from traditional industries, such as agriculture, textile and metal products, to very innovative and high value-added sectors, such as industrial machinery, transport equipment, electrical goods, pharmaceutical and chemical industries. With this important industrial basis, Slovenia has a very high export rate, that represents about 78% of its GDP, with about two thirds of its exports going to the EU internal market.

Figure 7.2.8 – Impact on annual long term GDP growth rate per country (in deviation from the reference scenario, left) and increase in R&D intensity (in % GDP, right)



Source: The NEMESIS model

When it comes to the evolution of the R&D intensity in the business sector in Slovenia, in the period 2007-2015 (see table 7.2.24), we observe that a large part of the +0.83 GDP point increase originates from the investments made by the Chemical and Pharmaceutical industries (+0.12 GDP point), the office machines sector (+0.12 GDP point), transport equipment industries (+0.04 GDP point) as well as the communications sector (+0.08 GDP point), with the largest increase in the other services sector (+0.3 GDP point) that includes the KIBS. It should be noticed that the R&D intensity increases in

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all sectors, thanks to very generous public support for the R&D investments of firms, re-enforced in 2012.

Table 7.2.24 – Evolution of R&D intensity in the business sector in Slovenia (in GDP points)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2015-2007
01 Agriculture	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
02 Coal and Coke	0.01%	0.01%	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%
03 Oil & Gas Extraction	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
04 Gas Distribution	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
05 Refined Oil	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
06 Electricity	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
07 Water Supply	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
08 Ferrous & non Ferrous Metals	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.03%	0.02%	0.01%
09 Non Metallic Min Products	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.04%	0.02%	0.02%	0.01%
10 Chemicals	0.32%	0.40%	0.41%	0.49%	0.50%	0.51%	0.50%	0.48%	0.44%	0.12%
11 Metal Products	0.03%	0.03%	0.04%	0.06%	0.07%	0.11%	0.09%	0.08%	0.07%	0.04%
12 Agricultural & Industrial Machines	0.03%	0.04%	0.04%	0.06%	0.09%	0.04%	0.05%	0.05%	0.05%	0.02%
13 Office machines	0.09%	0.11%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.09%	0.00%
14 Electrical Goods	0.07%	0.08%	0.12%	0.14%	0.18%	0.13%	0.25%	0.21%	0.19%	0.12%
15 Transport Equipment	0.08%	0.10%	0.10%	0.11%	0.15%	0.18%	0.13%	0.13%	0.12%	0.04%
16 Food, Drink & Tobacco	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%	0.02%	0.02%	0.01%
17 Textile, Clothes & Footwear	0.01%	0.01%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	0.01%
18 Paper & Printing Products	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%
19 Rubber & Plastic	0.01%	0.02%	0.02%	0.03%	0.03%	0.03%	0.03%	0.04%	0.03%	0.02%
20 Other Manufactures	0.02%	0.03%	0.03%	0.03%	0.05%	0.04%	0.04%	0.03%	0.03%	0.01%
21 Construction	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
22 Distribution	0.00%	0.00%	0.02%	0.02%	0.02%	0.02%	0.02%	0.03%	0.02%	0.02%
23 Lodging & Catering	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
24 Inland Transport	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
25 Sea & Air Transport	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
26 Other Transport	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
27 Communication	0.04%	0.04%	0.06%	0.07%	0.12%	0.12%	0.09%	0.13%	0.11%	0.08%
28 Bank, Finance, Insurance, Real Estate	0.00%	0.00%	0.00%	0.00%	0.03%	0.02%	0.03%	0.01%	0.01%	0.01%
29 Other Market Services	0.10%	0.12%	0.15%	0.19%	0.37%	0.56%	0.53%	0.44%	0.40%	0.30%
Total	0.85%	1.05%	1.17%	1.40%	1.79%	1.95%	1.99%	1.84%	1.69%	0.83%

Source: The NEMESIS model

Should these trends continue, they will allow Slovenia, provided its R&D intensity is maintained until to 2050 at the level reached in 2015 (2.21 GDP point), to increase its long term annual GDP growth rate by about 0.5 point (calculated over the period 2030-2050, see table 7.2.23).

The impact on EU trade When comparing the relative impacts of the evolution of R&D intensity across the different countries, an important aspect is the dynamics of intra- EU trade. Currently, the first competitors of EU firms are EU firms, competing in the EU market. Therefore, the firms in the EU countries with a pronounced rise in the R&D intensity, will increase their competitiveness relatively to firms in the internal market with a lower R&D intensity growth.

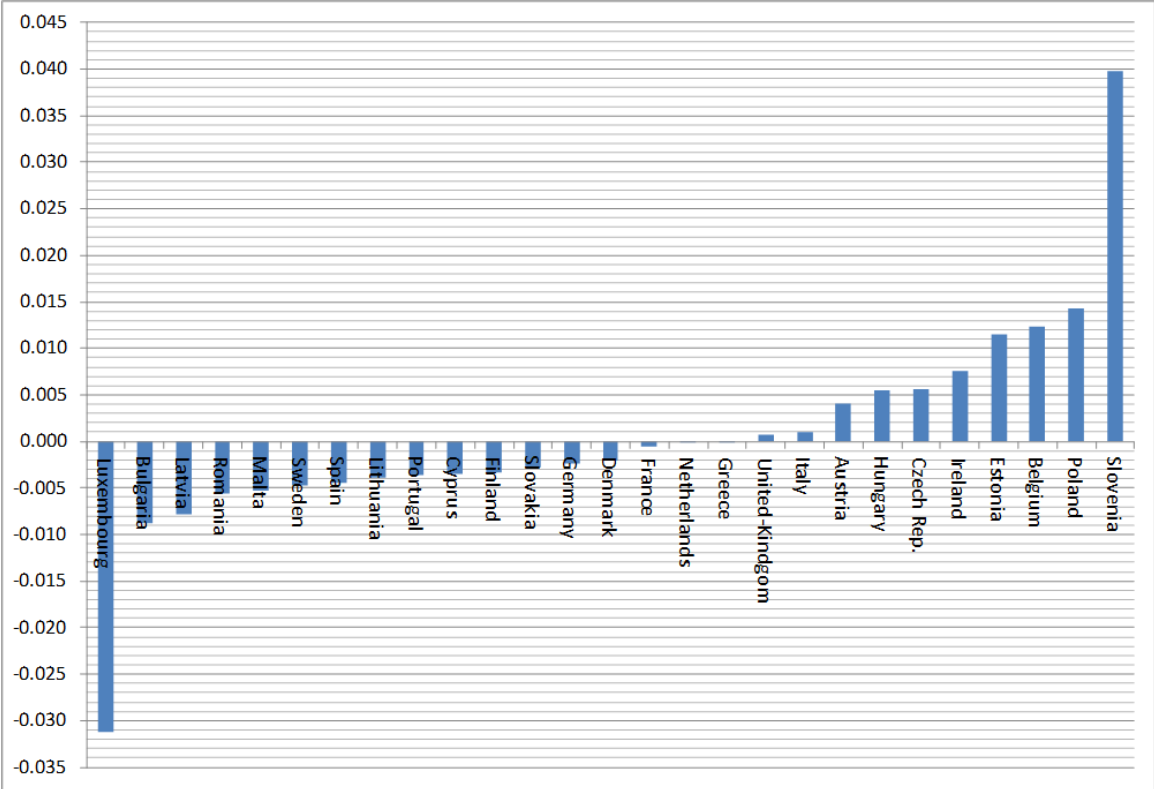
Returning to the case of Slovenia, that sends more than 70% of its exports to the EU market, Figure 9 shows that the rise of its R&D intensity over 2007-2015, if maintained in the future, could lead to an increase of net exports on the internal market of up to 4 GDP points in 2030.

In general, countries that increase their R&D intensity also generally improve their market share on the EU market. This is the case notably for Poland, Belgium, Estonia, the Czech Republic and Hungary.

With the inclusion of Ireland and United Kingdom, which have also improved their trade surplus on

the EU market, there are as many as 10 EU countries that will improve their relative competitiveness in the EU market in the long term, as a result of the positive impacts determined by the evolution of the R&D intensity between 2007 and 2015 (figure 7.2.9).

Figure 7.2.9 – Impact on Intra-EU trade balance in 2030 (in GDP points)



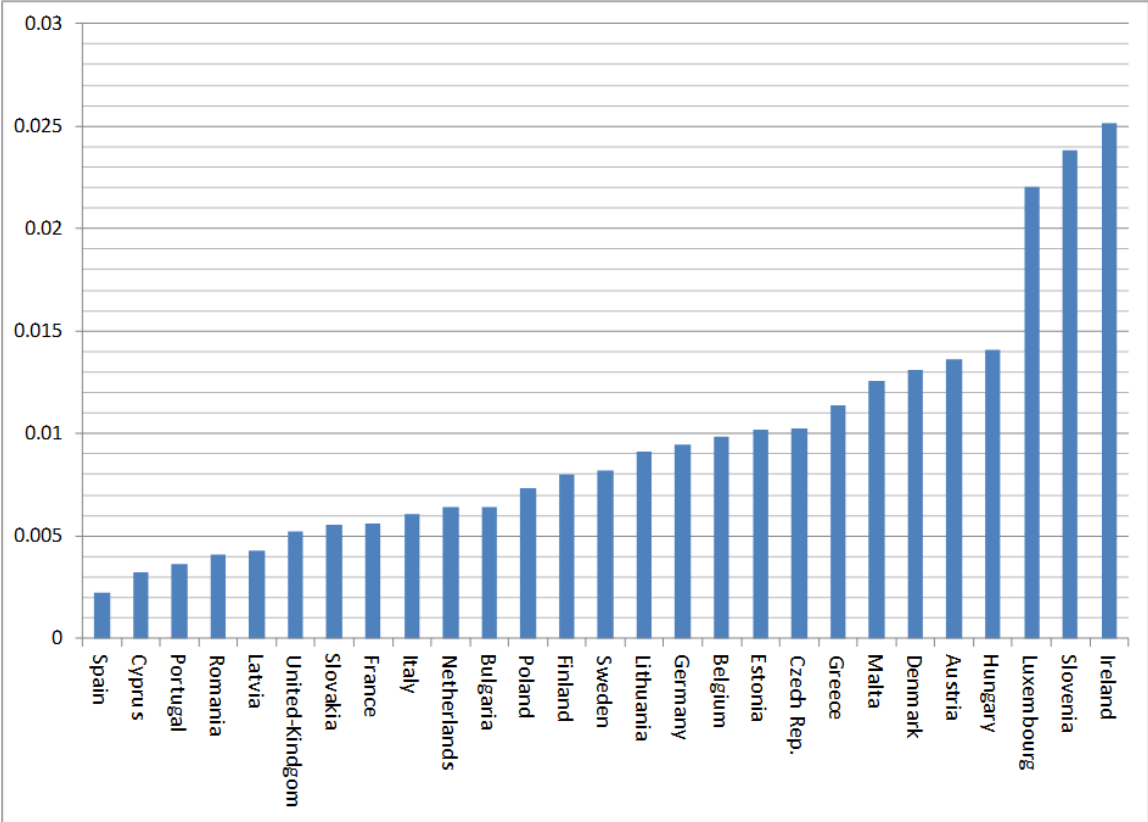
Source: The NEMESIS model

On the contrary, for the other EU countries, there will be limited or no impact on net exports on the EU market, like for Greece and the Netherlands, or negative impacts like for all the remaining countries. But while certain countries will see their relative position deteriorate on the EU market, all EU countries will improve their position in the world market. Figure 7.2.10 shows that the net export gains in world markets in 2030 will reach between +0.2 GDP point for Spain, and up to +2.5 GDP point for Ireland. Even a country like Finland, that reduced its R&D intensity between 2007 and 2015 by 0.45 GDP point, will experience a net gain in the world market by 2030 of about 0.8 GDP point.

The reason for this lies in the fact that while some countries lose their relative competitiveness in the EU market, the knowledge spill-overs that the different EU countries receive one from each other and the productivity transfers between each country still allows all of them to improve their position

on the world market.

Figure 7.2.10 – Impact on Extra-EU trade balance in 2030 (in GDP points)



Source: The NEMESIS model

Contributions to GDP increase in 2030 We have seen that external trade plays an important role on the GDP impact at country level.

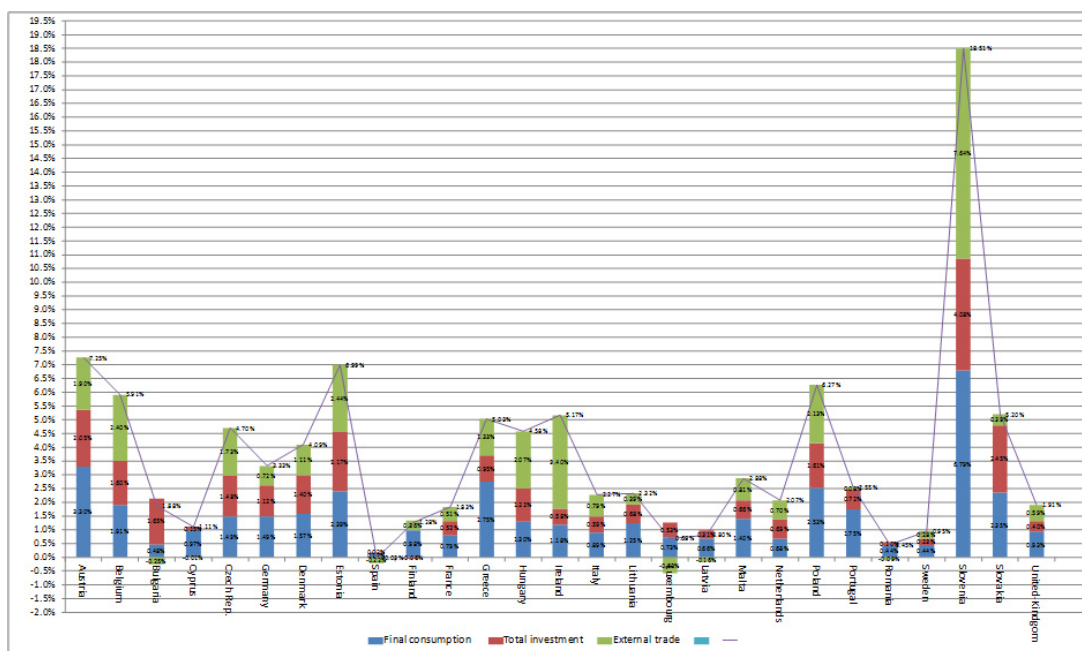
This is confirmed by Slovenia, where of the 18.5% GDP gains in 2030, about 7.6% (more than one third) will come from the improvement of its external balance (figure 7.2.11). The gain on external balance stimulates employment and final consumption, which will contribute for about 6.8% to the GDP gains in 2030, followed by investment, for the remaining 4.1 %.

For five countries (Bulgaria, Spain, Luxembourg, Latvia, Romania) the gain in competitiveness in the world market is insufficient to compensate for the losses in intra- EU trade, and the global contribution of trade on GDP remains negative in 2030.

Ireland is, after Slovenia, the country where the external balance contributes the most to the GDP increase, measured in 2030, with a contribution of 3.4 GDP points from external trade out of a total

gain of 5.2%.

Figure 7.2.11 – GDP gains and contributions per country in 2030 (in GDP points and in comparison to the reference scenario)



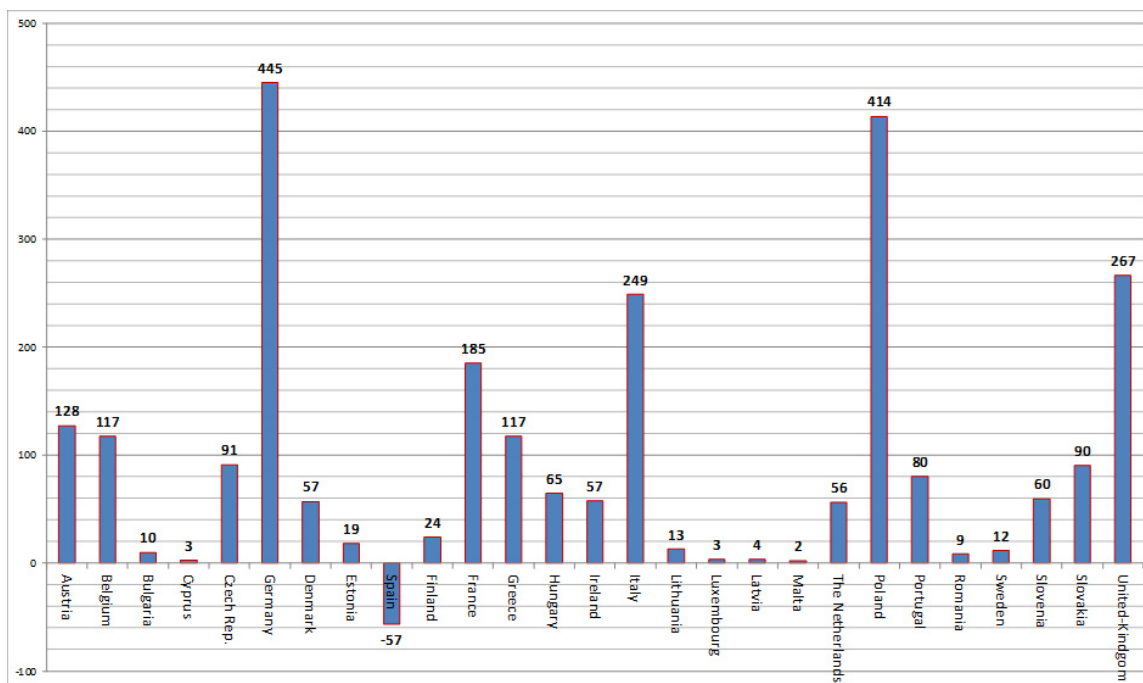
Source: The NEMESIS model

Impacts on total employment in 2030 Concerning employment at national level (see figure 7.2.12), the gains occur in the countries where the GDP increase is sufficient to compensate the productivity gains determined by process innovations and the substitution of capital by labor. These are also concentrated, in the largest countries (in terms of total population).

In 2030, only Spain loses jobs (-57000), while the other countries experience employment increases, from about 2000 in Malta, up to 4450000 in Germany.

Of the 2.52 million net job creations in the whole EU in 2030, 1.9 million (about 70% of the total) occur in 8 countries, where employment increases by more than 100,000, including, in addition to Germany: Austria (128,000), Belgium (117,000), France (185,000), Greece (117,000), Italy (249,000), Poland (414,000) and United Kingdom (267,000).

Figure 7.2.12 – Impacts on total employment in the different EU countries in 2030 (in thousands and in difference from reference scenario)



Source: The NEMESIS model

7.2.3.7 Summary of main findings with NEMESIS

The European Innovation Scoreboard represents a very useful instrument for assessing the innovation performance of EU countries and for monitoring the evolution of their research and innovation activities. Its system of 25 different research and innovation indicators provides a detailed representation of the situation prevailing in the various countries, but also allows for bench-marking of the different countries following three main dimensions: The “Enablers”, that capture the drivers of the innovation performance external to firms and the influence of the public action, “Firm activities” that measure the innovation effort at firm level and “Outputs” that reflect the impacts of firms’ innovation on their economic performance.

With NEMESIS, we focused on the analysis of two important indicators included in the EIS, that are the trends in R&D investments, in percentage of GDP, in both the public and the private sector. As we showed at the beginning of our analysis, the evolution of R&D investments is essential when explaining the modification in the innovation performance of the various countries on the period 2007-2015.

Then, starting from the real evolution of R&D investment by private firms on a detailed sector level (NACE Rev, second level) and of public R&D investments by socioeconomic objectives in every country, using the NEMESIS model, we calculated the economic and employment impacts of the trends in R&D intensities observed during this 2007-2015 period. This was done annually from 2008, and projected over a long-term period (2040).

Between 2007 and 2015, the total R&D intensity (in % on GDP) in the EU-28 increased 0.27 GDP point, that is split between +0.18 GDP point, for private R&D intensity, and + 0.09 GDP point for public R&D intensity. Nevertheless this global trend conceals various evolutions at country level. On the one hand, there are five countries where the R&D intensity decreased over the period 2007-2015, respectively Finland (-0.45 GDP point), Luxembourg (-0.30 GDP point), Ireland (-0.04 GDP point), Romania (-0.03 GDP point) and Spain (-0.01 GDP point). On the other hand, there are 7 countries where the R&D intensity increased between 0.45 and 0.79 GDP point, well above the EU average. They are Slovenia (+0.79 GDP point), Slovakia (+0.73 GDP point), Czech Republic (+0.64 GDP point), Austria (+0.63 GDP point), Belgium (+0.63 GDP point), Bulgaria (+0.52 GDP point) and Denmark (+0.45 GDP point). Four of these countries are eastern countries and this confirms the progress accomplished by some lagging countries, such as Slovakia, over the studied period.

Considering the analysis of the impact of these evolutions on the EU economy in the long-term, through the NEMESIS simulation, it may be said that for the year 2015, the rise in the R&D intensity between 2007 and 2015 contributed to the increase in EU GDP by about 0.74 GDP point. If after 2015, the R&D intensity in EU countries remains at the level reached in 2015, the GDP gains at EU level would increase up by 2.75% in 2030, and by 3.55% in 2040.

The impacts on employment at EU level were also been calculated by the NEMESIS model. They would reach 788,000 in full time equivalent in 2016, of which 521,000 are employment in research and 267,000 are additional jobs in activities of production. Of these latter, 339,000 are low skilled jobs, while the number of high skilled in production activities is reduced -7,2000, due to the rise in employment in the research sectors, that increases the real wage of high skilled. In 2030, the level of employment measured by the model is 2.52 million higher than its level in the reference scenario and the increase is 3.148 million for 2040.

At national level, the impacts on GDP are in line with the evolution of the R&D intensity during the period 2007-2015. In 2030 they range from 0% in Spain, that maintained roughly constant its R&D intensity in 2015 compared to 2007, up to 18.5% is Slovenia, that increased its R&D intensity

+0.79 GDP point, the most important increase in the EU-28.

Finally if we look more closely at the country level results, the simulation shows that it is the evolution of the external trade that drives most of the impacts on GDP and employment. Although all countries will increase their competitiveness and their position in the world market in the long term, some of them will experience a decrease or only a limited increase in their R&D investments, with loss of market shares in the EU internal market. This is the case, for example, for Spain, Luxembourg, Latvia and Romania, all countries for where the gains in the world market are insufficient to compensate for the losses occurred in intra-EU trade, and where the long-term impacts on GDP and employment, if positive, will nevertheless remain very limited.

7.2.4 Conclusion on the current state of the Europe Innovation Union based on the results of the I3U project.

The aims of the I3U project consisted, based on an in-depth analysis of the Innovation Union's 34 commitments, in gathering evidence on the impact of the EU innovation policy on growth and jobs in the EU and in the Member States, and forming recommendations on how this R&I strategy could be improved in the future.

Faced with the complexity of the European innovation strategy, with its forty commitments and sub-commitments, the analysis performed in I3U was organized around three groups of actions: (1) individual analysis of the commitments by expert teams, (2) elaboration of a conceptual model of the Innovation Union and the projection of the commitments actions into that system, (3) macro-sectorial modeling using NEMESIS, to take into account the overall interactions with the Eco-system, and determine the resulting impact on economic variables. For each of these three group actions, the following conclusions were obtained:

1. The individual analysis of the actions supported by the commitments revealed that they do not all pursue quantitative objectives with impacts on growth and job creation that could be measured. They are fourteen in this case. For eleven others, the data for measuring their state of implementation in the different Member States, or at EU level, are still missing, or not robust enough to provide a quantitative assessment of their action. Others are still not implemented, like the European patent (Commitment 14). There are finally only thirteen commitments for which a quantitative analysis is possible. Notwithstanding, merging different approaches for the analysis

of the different commitments, from conceptual and/or qualitative to purely quantitative, the first overall statement was that the commitments in the Innovation Union have for the most part been implemented and have begun yielding the desired effects. This is particularly true for the evolutions observed in the innovations coming from the KICs, the number of start-ups created and the number of graduates from the EIT. Important progress was achieved concerning the access to finance for innovators, and the creation of European Innovation Partnerships targeting global challenges and facilitating knowledge spillovers and linkages between innovation actors. However, the analysis shows that the different commitments have been implemented to different degrees. This is the case, for example, for the actions aiming at attracting and retaining foreign talent, at creating a European market for technologies, for improving and increasing the R&I share of structural funds, for promoting innovative public procurements, and for making innovation more inclusive;

2. The commitments' analysis could be strengthened by projecting them into the conceptual model of EU Innovation systems that was developed during the course of the project. Two main categories of commitments were distinguished, with a first group of fourteen that unequally address the specificities on the innovation systems of the EU Member States, and may lead either to convergence or to divergence of the innovation systems in the EU, depending if the weaker systems are more positively affected than the stronger, and *vice-versa*. Under the current practice and the currently observed trends, many of these commitments tend to increase the divergence. They concern actions going from University Ranking, to innovation funding and up to the development of collaborations with third countries, that all bring benefits, in first place, to the most-developed and publicly-led innovation systems. A second group of seven commitments affects the weaker innovation systems more positively than the strongly developed systems. They go from the Eco-Innovation Action Plan, to Europe Creative Industries Alliances, up to Smart specialization. They are almost exclusively commitments that act on interactions between actors or conditions of the system, while, on the contrary, the commitments in the first group are actions leading to divergence and are aimed at developing the capabilities of actors. The situation could be reversed by focusing more explicitly on the capabilities of actors in lagging or developing innovation systems, but in the current Innovation Union, the capabilities of advanced actors seem to be most often targeted;

3. Then building on the indicators from the European Innovation Scoreboard, that measure the progress of the Innovation Union, and focusing on the evolution of both private and public R&D investments in the different Members States at a detailed level, the NEMESIS model could provide a first quantification of the growth and employment impacts of the progress of the Innovation Union from the pre-crisis period up to 2015. This model relies on the diversity of interactions it is able to represent between the different productive sectors, the different economic agents, and the different countries. These interactions are, for example, the exchange of innovative production goods and services, that diffuse the positive effects of innovations from the sectors that develop and manufacture the innovations, to the sectors and the countries that use them (rent spillovers). There is also the positive influence of knowledge spillovers, that are represented in the model both in the inter-sectorial and international dimensions. Finally, there is the structural change that innovations create on household consumption. Another advantage of the analysis provided by the model, compared to the other approaches that were used for the project, is that it can evaluate the effects of R&I policies from the short- to medium- and long-run, which is very important as it takes about 15 years between the time policies are introduced, and the time they produce their full impacts on the economy at large. We won't comment on the simulation results again, and will simply note for illustration that the model results show that the rise of about 0.3 GDP point in the R&D investments in the EU countries after the financial crisis, if maintained in the future, could create 2.5 million new jobs by 2030, and increase the level of EU GDP by 2.75%, and its long-run annual growth rate by 0.07%.

7.3 What are the perspectives under current trends?

The second question which the research teams involved in the I3U project aimed to answer, is what progress could be expected from the Implementation of the Innovation Union in the future, and what would the impacts on the EU economies be?

The answer to this second question supposes that the socioeconomic impacts of the individual commitments could be quantified, and that any potential overlapping could be identified in order to avoid double-counting certain impacts when assessing the commitments by groups, and then as a whole to provide a global picture of the overall impacts of the Innovation Union.

The analysis was therefore necessarily limited to the set of 13 commitments, listed in table 7.1.4,

for which it was possible to assign quantitative aims, and to obtain sufficiently robust data for their quantitative analysis.

This work was the result of a long process, built on the results of the Conceptual model on the action of individual commitments, of their potential overlapping, and on the work delivered by the commitments expert teams on the evaluation of their direct impact assessment, in terms of various research and innovation outcomes, using data collection and analysis, and various statistical and analytical works. We then retrieved a certain number of data and parameters from these works, that were used to modify and re-calibrate certain mechanisms in the NEMESIS model, to describe the actions of each commitment on the innovation system of each country in it. Thus the model could take into account interactions of the commitments with the ecosystem, and provide a projection in time, up to 2050, of their potential impacts on the economy at large.

At the end of this process, four groups of information were provided by the commitments' expert teams to SEURECO in charge of the implementation of the commitments in the NEMESIS model:

1. **Data and parameters:** In a first stage, the commitments experts provided SEURECO with the required data and parameters to describe the direct impacts of the commitments in the NEMESIS model. As we underlined, this collection of data and parameters was restricted to the thirteen commitments for which 0relevant data (even proxy data) and robust econometric results exist. The use of econometric techniques was necessary for all commitments except for commitments 6, 14, and 24/25.
2. **Inputs for sensitivity analysis:** Alternative sets of variables and/or parameter values were used in order to perform sensitivity analysis on the commitments impacts, as well as to provide high and low values for impacts. For example, for econometric parameters, the sensitivity analysis used, besides the mean value of the parameters that were estimated, high and low values that were calculated by adding to or subtracting from, the standard deviation once from the mean value. In this way we obtain an (about) 60% confidence interval for the “*true*” value of the parameter, and for the impacts measured using the NEMESIS model.
3. **Definition of a “*REALISTIC*” scenario:** The commitments experts were asked, based on the recent trends, to provide assumptions on the % increase of the implementation of their commitments that could be reached in the future, up to 2027. Then a “*REALISTIC*” scenario was built where, by assumption, the implementation of commitments, between 2014 and 2027, follows

currently observed trends. After 2027, by assumption, the implementation of the commitments remains constant, up to 2050, at the level attained in 2027.

4. **Definition of an “OPTIMISTIC” scenario:** To contrast the “REALISTIC” scenario, the commitments experts were also asked to provide assumptions on any additional increase, compared to the evolution in the “REALISTIC” scenario, that could reasonably be reached by the implementation of their commitments. Like for the “REALISTIC” scenario, the “OPTIMISTIC” scenario sets targets up to 2027, and then, after 2027 up to 2050, the commitment implementation is supposed to remain constant, at the level attained in 2027. This scenario, more “volontarist” than the preceding, was designed in such a way to remain plausible, but it assumes the implementation of additional policies or the amplification of the policies already in place.

With these four sets of information, it was therefore possible, when evaluating using NEMESIS the commitments individually, by group, or as a whole, to provide two main scenarios showing the development of their potential impacts on the EU economies in the future:

1. The first under current observed trends, up to 2013, on the progress accomplished in the implementation of the commitments in the different countries;
2. The second amplifies these trends to project a more optimistic picture that nevertheless remains realistic and takes into account possibilities for improving the current EU R&I strategy.

If we also take into account the sensitivity analysis that was performed to border the results of the model, six simulations were run for each of the thirteen commitments, for each of the four commitments groups that were considered, and for assessing the impact of the commitment as a whole. This represents 108 different simulations in total. The interested reader could obtain all the detailed results (for the different countries/sectors and the EU as a whole) under Excel format in Le Mouël *et al.* (2019, [208]).

Here, we will simply propose of synthesis of the main results, focused on the assessments of the Innovation Union “*as a whole*”. We will then describe the methodology of implementation of the commitments in the model for every commitment, but we will select some representative examples for each of the four commitment groups.

Finally, the macro-sectorial evaluation of the Innovation Union and the thirteen “*selected*” commitments, we present here, focus on the progress in the Innovation Union during the period covered by the

current EU multiannual framework financial perspective (2013-2020), and by the next one for 2021-2027. The simulations that we present are therefore at the same time ex-post, interim and ex-ante, as they are based on data up to 2015-2016, that is to say the mid-period covered by the current Europe 2020 strategy and its Innovation Union initiative flagship. We are also interested by the progress that could be reached during the next financial perspective, as the current Innovation Union flagship initiative will be soon reshaped, and in that perspective certain simulation results could provide indications on the way to re-orient the EU R&I strategy for future years. Finally, after 2027, it is assumed that no further progress will be accomplished by the EU R&I strategy, to appreciate the long-run impact of what was already done, or could be reached, from the last five years up to the next eight years.

We will now illustrate the general methodology that was used to implement the Innovation Union commitments in the NEMESIS model, and then turn to the presentation of the synthesis of the main results.

7.3.1 Implementation of Innovation Union Commitments in NEMESIS

Table 7.1.4 summarizes, for the thirteen commitments implemented in the NEMESIS model, the type of variables used by the commitments expert teams to measure their “*degree*” of implementation, and their “entry” in NEMESIS, that is to say the innovation mechanisms of the model that are the most directly impacted by the action of the commitments.

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Table 7.3.1 – Summary table of commitment’s implementation in the NEMESIS model

WP number (Team)	Commitments	Commitment category	Commitment entry in NEMESIS	Variables used to measure the commitment (source)
1 (TIK)	2.2 - "Knowledge alliances for skill gap"	Group 1 - "Human Capital"	Public research economic performance	Knowledge transfers between companies and universities - survey response (IMD Competitiveness Database)
1 (TIK)	3 - "Propose an integrated framework for e-skills"	Group 1 - "Human Capital"	Public research economic performance	Proportion of workers with ICT user skills (Eurostat)
2 (TIK)	4.2 - "ERA - Research Mobility"	Group 1 - "Human Capital"	Public research economic performance	Share of researchers currently employed in another country than their country of citizenship (MORE2)
2 (WERI)	6 - "EU Research and Innovation Programmes"	Group 3 - "EU Funds"	Private and public R&D investments decision & public and private research economic performance	EU R&I Budget - MFF (European Commission)
3 (ULB)	10 - "Put in place EU-level financial instruments to attract private finance"	Group 2 - "Access to finance"	Private R&D investment decisions	Budget of EU financial instrument for innovation (EIB)
3 (ULB)	11 - "Access to Finance - Venture Capital"	Group 2 - "Access to finance"	Private R&D investment decisions	Number of EuVECA fund operations per year (EUVECA) and Investment/rounds (Dealroom)
3 (ULB)	12 - "Access to Finance - Matching"	Group 2 - "Access to finance"	Private R&D investment decisions	Business Expenditures for Research and Development by abroad (Eurostat)
3 (ULB)	13 - "Review State Aid Framework for R&D&I"	Group 2 - "Access to finance"	Private R&D investment decisions	General Block Exemption Regulation to RDI (European Commission)
3 (ULB)	19.1 - "Creative Industries"	Group 4 - "Action to market"	Private R&D investment decisions	Business expenditures on R&D by the Creative Industries (Eurostat)
5 (ULB)	19.2 - "European Design Leadership Board"	Group 4 - "Action to market"	Private R&D investments decision	Value of new Community Designs registered (Eurostat)
6 (WIIV)	24/25 - "Maximising Social and Territorial Cohesion"	Group 3 - "EU Funds"	Private and public R&D investments decision & public and private research economic performance	European Structural and Investments funds to support R&I - MFF (European Commission)
7 (TIK)	30 - "Retaining and Attracting International Talent"	Group 1 - "Human Capital"	Public research economic performance	Survey responses reflecting the perceptions of global business executives (IMD Competitiveness Database)

*: *Le Mouel et al. (2019, [206])*

We see from table 7.1.4 that the four groups of commitments that we distinguished, regroup commitments that have similar action on the mechanisms of the model: The commitments of group 1, “*Human capital*”, increase research performance; the commitments of Group 2, “*Access to finance*”, increase private R&D investment decisions; the commitments of group 3, “*EU Funds*”, increase public and private R&D investments and the economic performance of private research; and the commitments of Group 4, “*Action to market*”, also have a positive feedback on private R&D investments.

These impacts of the commitments on the innovation mechanisms of the model are only “*direct*” ones, whose measurement results from the works that were performed by the teams in charge of the direct impacts assessment of the different commitments. But the commitments will modify the innovation behavior of firms in many additional channels in the model, for example the knowledge externalities generated by public and private R&D investments, the ripple effect that R&D investments have on investments in other innovation assets (ICT, Training and Software), and the rent spillovers provoked

by innovations that will diffuse between sectors and countries.

In this section, we will focus on a few examples of the way the direct impact of the commitments by the expert teams was made, and how the inputs that were needed to enter their impact in the model were produced, that involve:

- The information needed to build a “*Realistic*” or “*Current*” trend scenario, with “*Medium*”, “*High*” and “*Low*” values of the data and/or the parameters, so as to border the model’s results;
- Similarly, the information needed to build an “*Optimistic*” or “*More ambitious*” scenario, and also to perform sensitivity analysis.

To illustrate our methodology, so it is representative of the work achieved for each commitment, we will use at least one example for each of the four commitment groups.

7.3.1.1 Implementation group 1 commitments: “*Human capital*”

The direct impact assessment of the four commitments under the thematic “Human capital” was achieved by TIK under the direction of Fulvio Castellacci (See Castellacci *et al.*, 2017, [55]). What they have in common is to act in the model mainly by influencing the productivity of the public research positively, in universities or research institutes. In terms of model mechanisms (table 7.3.2), they modify the value of the spread parameters that measure the strength and direction of knowledge spillovers from public research

Table 7.3.2 – Modification of NEMESIS model to implement Group 1 commitments

Commitment	WP	Team	Thematic	Entry/mechanisms in NEMESIS
2.2 Knowledge alliances for skill gaps	1	TIK	Human capital	1- Spread parameter for public R&D (P4 in table 4.4.1) that measures the strength and direction of knowledge spillovers from public research: α_{ps}
3 Propose an integrated framework for e-skill	1	TIK	Human capital	1- Spread parameter for public R&D (P4 in table 4.4.1) that measures the strength and direction of knowledge spillovers from public research: α_{ps}
4.2 ERA - research mobility	2	TIK	Human capital	1- Spread parameter for public R&D (P4 in table 4.4.1) that measures the strength and direction of knowledge spillovers from public research: α_{ps}
30 Foreign talents	7	TIK	Human capital	1- Spread parameter for public R&D (P4 in table 4.4.1) that measures the strength and direction of knowledge spillovers from public research: α_{ps}

Source: Le Mouél et al. (2019, [206])

As for example, we take the case of commitment C2.2, “Knowledge alliances for skill gaps”, that calls for university-industry collaborations to foster the development of entrepreneurial skills among tertiary students. The main difficulty, as reported by Castellacci *et al.* (2017, [55]) is that we do not have any direct indicators to measure the implementation of this commitment, obliging us to use a more general proxy of the links between universities and industries in European countries.

The integration of this commitment in NEMESIS was therefore based on an econometric estimation with, as dependent variable, the number of scientific and technical articles per 1000 R&D full-time equivalent employees and, as explanatory variable, the current degree of knowledge transfers between

companies and universities, using an indicator available in the IMD Competitiveness Database (See Castellacci *et al.*, 2017, [55], table 3 page 37). This latter variable is a survey response reflecting the perceptions of global business executives on a 1 to 10 scale – degree of agreement. The data cover the period 1995 to 2016 and are for every EU-28 countries. The estimation includes control variables and the results used for NEMESIS are those for the fixed effect parameter for the whole sample (See Castellacci *et al.*, *ibid*, table 18 page 65). The estimated value of the parameter is 9.64, with a standard deviation of 3.37.

Using the mean values of the variables at EU level, we could see that:

- In the “*Medium*” case, a 1% increase of knowledge transfers increases the productivity of public research by 0.29%.
- In the “*Low*” case, by retrieving the standard deviation of the parameter estimated, elasticity is equal to 0.19.
- In the “*High*” case, adding symmetrically the standard deviation of the parameter estimated, elasticity is equal to 0.39.

The data show an average increase of 1.2% per year of the variable knowledge transfers in EU28, during the 1995-2016 period. Therefore:

Table 7.3.3 – Evolution of the variable “Knowledge transfers” in the “REALISTIC” and “OPTIMISTIC” scenarios

	Knowledge transfers between companies and universities (survey responses, 1-10 scale, 1: minimum and 10: maximum)						Mean value (1995-2016)	Value REALISTIC scenario (2027)	Value OPTIMISTIC scenario (2027)
	1995	2000	2005	2010	2015	2016			
Austria	5.1	4.8	5.4	6.8	5.5	6.2	5.6	7.1	8.4
Belgium	4.6	5.0	5.5	6.2	6.6	6.6	5.6	7.2	8.5
Bulgaria	3.7	3.7	3.7	2.6	2.5	3.1	3.3	3.0	3.5
Croatia	2.8	2.8	2.8	2.6	2.2	2.8	2.7	3.0	3.6
Czech Republic	3.3	3.0	5.0	4.6	4.3	4.0	4.0	4.1	4.8
Denmark	4.4	4.9	5.8	6.6	7.0	7.1	5.9	8.2	9.7
Estonia	3.7	3.7	3.5	5.0	5.0	5.3	4.2	5.8	6.8
Finland	6.2	6.9	7.3	6.8	7.0	6.9	7.0	8.8	10.0
France	4.6	4.4	4.4	4.7	5.2	4.8	4.6	5.9	6.9
Germany	5.3	5.3	4.9	6.7	6.8	6.7	5.8	8.2	9.7
Greece	2.5	3.1	3.7	3.3	3.5	3.6	3.4	3.9	4.6
Hungary	2.9	4.8	5.6	4.2	3.9	4.2	4.3	5.2	6.2
Ireland	4.6	5.4	5.7	6.3	6.2	6.1	5.8	7.5	8.9
Italy	2.8	2.9	3.1	3.8	4.0	4.5	3.4	4.4	5.2
Latvia	3.8	3.8	3.8	3.8	4.2	3.6	3.9	5.2	6.1
Lithuania	4.6	4.6	4.6	4.6	4.5	5.3	4.6	5.0	5.8
Luxembourg	4.6	4.2	3.4	5.3	6.1	6.1	4.7	7.1	8.4
The Netherlands	4.9	6.0	5.8	6.6	6.9	7.4	6.0	8.2	9.6
Poland	2.7	4.2	3.5	3.4	3.0	2.7	3.3	4.0	4.7
Portugal	3.0	3.0	3.8	3.8	4.5	4.9	3.6	4.4	5.2
Romania	3.6	3.6	3.0	3.8	4.6	6.0	3.9	4.6	5.5
Slovak Republic	4.6	4.6	3.8	2.7	3.0	3.3	3.7	3.2	3.7
Slovenia	2.4	2.5	3.0	3.6	3.2	4.2	3.1	3.8	4.5
Spain	3.0	3.2	3.6	3.8	4.1	4.1	3.7	4.8	5.6
Sweden	5.7	5.7	5.7	6.9	6.2	6.9	6.2	8.0	9.4
UK	4.8	4.4	4.2	6.4	6.9	6.8	5.2	7.8	9.1
EU28 average	4.0	4.2	4.4	4.8	4.9	5.1	4.5	5.7	6.7

Source: IMD Competitiveness Database, see I3U deliverable D.1.2 for details and authors' calculation. Note: in red, missing data set at last known value

- For the “REALISTIC” scenario, we considered that knowledge transfers could increase again by 1.2% per year, on average, between 2013 and 2027 in every EU country. This leads to an increase of 18% over the period.
- For the “OPTIMISTIC” scenario, we assumed that the annual increase could double and reach 2.4% per year during the period, leading to a cumulative increase between 2013 and 2027 of 39%.

We see from table 7.3.3 that on a scale from 1 to 10, under current trends (“Realistic” scenario),

transfers in Europe would increase on average from a mean value of 4.5 for the period 1995-2006, up to 5.7 in 2027, and to 6.7 in the more ambitious scenario. We must underline that with the methodology used to project the action of the commitments in the model, the large discrepancies existing today in the importance of knowledge transfers between countries with the stronger and the weaker innovation systems, are supposed to continue to exist in the near future. The model results, like for the analysis performed based on the Conceptual model of the Innovation Union, confirm that this commitment favors the innovation systems with the more advanced actors and increases divergence between EU Member States¹⁸.

7.3.1.2 Implementation group 2 commitments: “*Access to finance*”

What this second group of commitments, “*Access to finance*” has in common is that they are linked to policy instruments aimed at facilitating innovative firms access to finance. This consists in putting into place new financial instruments, like for commitment 10, widening the access to existing instruments, like for commitments 11 and 12, or facilitating access to public funding, like for commitment 12. Their direct impact assessment was made by the ULB, and coordinated by Michele Cincera (See Cincera and Santos, 2018, [59]). Their actions in NEMESIS (See table 7.3.4) come from their impact on the R&D investments by private firms, that will also exert “*pulling*” effects on the investments in the other innovation assets: ICT, training and Software .

As an example, for this group we take the case of commitment 11, “*Access to finance - Venture capital*”. Its action passes through the introduction of the EU Venture Capital Fund (EuVECA) in 2013, at the initiative of the European Commission. Based on the statement that Venture capital is under-developed in European countries, and that start-ups and small firms have difficulties in financing their R&D and industrialization, the EuVECA offers rearranged fiscal rules for investors. This was reformed in 2016 to make it even more attractive for European Venture capitalists.

¹⁸The GDP gains in 2040 under the current trend scenario range for example from 0.39% in Austria, 0.34% in Sweden and 0.29% in Denmark, to 0.01% in Latvia with even negative impacts in Poland (-0.02%) and Slovakia (-0.04%). See Le Mouél *et al.* (2018, [207]), or follow this link for the full model results: <http://www.i3u-innovationunion.eu/wordpress/wp-content/uploads/2018/09/I3U-C2-2-NEMESIS-RESULTS.xlsx>

Table 7.3.4 – Modification of NEMESIS model to implement Group 2 commitments

Commitment	WP	Team	Thematic	Entry/mechanisms in NEMESIS
10 Put in place EU financial instruments to attract private finance	3	ULB	Finance	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: J_{cit}^* , with j standing for R&D, ICT and OI.
11 Access to finance- Venture capital	3	ULB	Finance	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: J_{cit}^* , with j standing for R&D, ICT and OI.
12 Access to finance - Matching	3	ULB	Finance	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: J_{cit}^* , with j standing for R&D, ICT and OI.
13 Review State aid framework for R&D and innovation	3	ULB	Finance	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: J_{cit}^* , with j standing for R&D, ICT and OI.

Source: Le Mouél et al. (2019, [206])

The direct impact assessment of this commitment was based on an econometric estimation using the investments in R&D by private firms (BERD) in million Euros 2016, in the EUROSTAT data, as a dependent variable, and the number of European Venture Capital funds (EuVECA), marketed in all EU member states over the period 2013 to 2016, in the ESMA¹⁹ database, as an explanatory variable. The estimation included control variables and used a pooled-OLS and fixed effects panel data regression model. The value of the parameter estimated is 0.0076, with a standard deviation of 0.00306 (See Cincera and Santos, 2018, [59], table 5 page 22).

Using the mean value of the variables at EU level, we could see that:

- In the “Medium” case, one additional EuVECA operation (or “round”) increases EU BERD by

¹⁹European Securities and Markets Authority

€3.7 million;

- In the “*Low*” case, taking into account the value of the standard deviation, this marginal effect is equal to €2.2 million;
- For the “*High*” case, the marginal effect is equal to €5.2 million.

A major difficulty was that the person responsible for the data at ESMA, could not provide any information on the average financing accorded by EuVECA operation. Only the total number of operations by year and by country was available.

To overcome this difficulty, another data source, broader than the data collected at ESMA, was used. This source is the Dealroom (2017, [95]), Europe’s leading venture capital database, that tracks over 500,000 high growth companies and 10,000 investors in Europe and beyond. The data show, like for the ESMA data, an important development in the number of VC operations (rounds), that grew from 1,290 in 2012 to 3,376 in 2016, with 2,241 operations per year over the 2012-2016 period on average. From the ESMA data, the number of operations passed from 44 in 2013 to 835 in 2016, with 413 operations per year on average during the 2013-2016 period (see table 7.3.5)

Table 7.3.5 – Venture capital data from Dealroom and ESMA

	2012	2013	2014	2015	2016	mean/year
Total investment (billion euro)	4.2	4.9	10.1	14.4	16.2	10.0
Number of Venture Capital operations	1290	1853 (+44%)	2120 (+14%)	2566 (+21%)	3376 (+32%)	2241
Number of Venture Capital Operations (ESMA database)	-	44	233 (+430%)	541 (+132%)	835 (+32%)	413
Investment/rounds (million euro)	3.26	2.64	4.76	5.61	4.80	4.21

Source: Dealroom (2017, [95])
Note: annual growth rate in brackets

Concerning the amount of investment financed by each operation, it appears from Dealroom data to be equal to €4.2 million on average. This figure therefore validates the marginal value of the BERD investment financed by each additional operation, estimated by Cincera and Santos (2018, *ibid*), and that is €3,7 million in “*Medium*” case, and respectively €2.2 and €5.2 million in “*Low*” and “*High*” cases.

Table 7.3.6 – Assumptions used to implement commitment 11 in NEMESIS

		Reference scenario	Low		Medium		High	
			Realistic	Optimistic	Realistic	Optimistic	Realistic	Optimistic
Number of EuVECa fund operations per year	2014-2016	45	536	536	536	536	536	536
	2017-2020	48	1 466	1 552	1 466	1 552	1 466	1 552
	2021-2027	52	1 767	2 312	1 767	2 312	1 767	2 312
	2028-2050	65	2 185	2 910	2 185	2 910	2 185	2 910
National Allocation	2014-2016	National share of EU BERD	Based on historical data					
	2017-2050	National share of EU BERD	National share of EU BERD					
Average amount invested in R&D for each EuVECa fund operation (euro constant 2016)		€ 3.7 million	€ 2.2 million		€ 3.7 million		€ 5.2 million	

Source: Dealroom (2017, [95])
 Note: annual growth rate in brackets

The full set of assumptions used to implement commitment 11 in the NEMESIS model, and to build the “*Realistic*” and “*Optimistic*” scenarios are summarized in table 7.3.6. The reasoning was as follows:

- For the reference scenario of NEMESIS, with which the simulation results are compared, we considered that number of VC operations would not have reached the great increase in the 2014-2016 period we just described. Rather we assumed that this number will have grown like the EU GDP, up to 2050, at about 1.4% per year. Using this assumption and by multiplying the number of operations by the average amount of investment financed by operation, R&D investments financed by the EuVECA funds in percentage of EU GDP, in this reference scenario, remain unchanged. For the national allocation, like for RiskFinance, there exists a very high linear correlation between the share of EuVECA operations per country in the whole of EU, and the share of each country of all EU BERD investments, with a correlation coefficient equal to 0.94.

So we used the share of each country of the total EU BERD investments to allocate the EuVECA operations to the different countries.

- For the “*REALISTIC*” scenario, the number of operations per country comes from the historical data provided by the ESMA database. For the period between 2017 and 2027, we retained the assumption that the total number of operations over the period will double compared to the level in 2016(+835), leading to 1,670 operations in 2020. Furthermore we supposed that this progressive increase has a symmetric profile with the evolution of the number of operations between 2013 and 2016. It therefore increases at a decreasing rate up to 2020, and after 2020, by assumption, the number of operations will follow the growth of EU GDP, with the EuVECA funds stabilizing in % of GDP.
- For the “*OPTIMISTIC*” scenario, for 2014 to 2027 we extrapolated the same annual growth rate as for the EuVECA funds over the period 2013-2016. For that period, the number of operations grew rapidly but with a decreasing rate of growth: it slowed down by 31% each year. By extrapolating this trend up to 2027 (i.e. the number of operations will continue to grow at decreasing rate up to 2027), the number of operations reached in 2027 is 2,249, against only 1,839 in “*REALISTIC*” scenario.

With all these assumptions, from 2027 to 2050, the EuVECA funds should respectively represent 0.039% of EU GDP in the medium case of the “*REALISTIC*” scenario, that is to say with the assumption that each operation finances €3.7 million investment (Mean estimate). In the “*Low*” case, it will be 0.023% of EU GDP and 0.054% in the “*High*” one. For the “*OPTIMISTIC*” scenario, the values will respectively be 0.031%, 0.052% and 0.073% of EU GDP. Obviously, these figures are calculated in difference with the amount of EuVECA funds in percentage GDP in the reference scenario that is very weak, and fixed at 2013 level.

We must underline that the national allocation of the EuVECA fund that we retained goes with the observation that these funds were concentrated in a few EU-15 countries, the most R&D intensive. The assessment of this commitment using NEMESIS is therefore well in line with the conclusions that were obtained from the Conceptual model of the European Innovation systems, and that these funds, as well as the actions supported by commitments 10 and 12, would mostly benefit firms belonging in countries with the strongest innovation systems²⁰.

²⁰The GDP gains in 2040 under the current trend scenario range actually from 1.20% in Sweden, 1.17% in Austria and

7.3.1.3 Implementation of the group 3 commitments: “European funds”

This third Group of commitments includes commitments 6 and 24/25 of the Innovation Union, related to European funds that support R&I investments: the current Horizon 2020 and next Horizon Europe EU R&I Research Programmes, as well as the European Structural and Investment Funds (ESIF) supporting R&I activities.

Commitment 6 - “*EU Research and Innovation Programmes*”, assumes that Horizon 2020 and the next EU R&I Programmes (Horizon Europe for the 2021-2027) are an essential part of the EU research and innovation policy and that the scope, theme and extent of the Programmes must follow and support Innovation Union objectives. Furthermore, this commitment considers that “*future programmes should focus more on societal challenges, streamline funding instruments and radically simplify access through a better balance between a control-based and a trust-based system*”.

Commitment 24/25 – “*Improve the use and increase the share of structural funds for research and innovation*”, considers that the use of the European Structural and Investment Funds for research and innovation must be improved by helping people to acquire necessary skills, improving the performance of national systems and reinforcing synergies with EU R&I Programmes. In addition, the commitment requires an increase in the Structural and Investments Funds focusing on innovation and smart specialization, especially through the European Regional Development Fund (ERDF) that should further commit substantial financial resources to supporting innovation initiatives within the regions of the European Union.

The direct impact assessment of these commitments was achieved by the WERI and coordinated by Marzena Anna Weresa for commitment 6 (see, Kowalski *et al.*, 2017, [199]), and by the WIIW and coordinated by Sandor Richter, for commitments C24/25 (see Mackiewicz *et al.*, 2018, [226]).

They will act in the NEMESIS model (see table 7.3.7) mainly because of their impact on R&D investment by private firms and public authorities. Firstly, support for R&I investments will directly impact R&D investment decisions and public R&D expenditures. Secondly, the direct crowding-in (or crowding-out) effect of R&I financial support on private and public R&D expenditures, also impacts R&D investment decisions and public R&D expenditures. Furthermore, according to the assumption about the EU Added-Value of the Research and Innovation activities supported by EU compared with

0.92% in Finland, to 0.1% in Latvia, 0.08% in Lithuania and 0% in Slovakia . See Le Mouél *et al.* (2018, [207]), or follow this link for the full model results: <http://www.i3u-innovationunion.eu/wordpress/wp-content/uploads/2018/09/I3U-C11-NEMESIS-RESULTS.xlsm>

similar activities supported at national level, the productivity of research will be modified marginally in the model.

Table 7.3.7 – Modification of NEMESIS model to implement Group 3 commitments

Commitment	WP	Team	Thematic	Entry/mechanisms in NEMESIS
6 EU Research and Innovation Programmes	2	WERI	European Funds	1- Optimal demand of innovation inputs from equations E1 in appendix 8: J_{cit}^* , with j standing for R&D 2- Public expenditure on R&D 3- Productivity parameters of innovation inputs: P5-1 in appendix 8
24/25 Improve the use and increase the share of structural funds for research and innovation	6	WIIW	European Funds	1- Optimal demand of innovation inputs from equation E1 in appendix 8: J_{cit}^* , with j standing for R&D 2- Public expenditure on R&D 3- Productivity parameters of innovation inputs: P5-1 in appendix 8

Source: Le Mouél et al. (2019, [206])

These FP programmes and the ESI funds are a very important share of the EC budget and its support for R&I activities, and here we will describe the way both were implemented in the model.

EU research and innovation programmes - Commitment 6 For the interim evaluation of the socioeconomic impacts of H2020 programme in chapter 6, and of the ex-ante impact assessment of the next Horizon Europe programme in chapter 4, the following questions had to be solved in order to integrate commitment 6 in NEMESIS:

1. What is the financial EU R&I support and how is it financed and spent?
2. What is the total R&I expenditure created by the financial public support of the EU R&I Programme? Is there a crowding-in or crowding-out effect on private or public R&D expenditures?
3. Is there an EU added-value coming from the European R&I Programmes compared to national

ones and how much is this EU added-value?

The first question refers to the EU R&I budget and its allocation between (i) “*Applied*” and “*Basic*” research, (ii) member states and (iii) economic sectors. As for previous commitments, we distinguished three scenarios: “*REFERENCE*”, “*REALISTIC*” and “*OPTIMISTIC*”, then three separate cases for the two latter scenarios: “*High*”, “*Medium*” and “*Low*”. The major difference between the three scenarios is the different budgets for the EU R&I Programmes (see table 7.3.8) that summarizes all the assumption used to implement the FP programmes in the model):

- In the “*REFERENCE*” scenario, it was assumed that after the 7th FP, the financial support is constant per unit of EU GDP from 2014 to 2050, starting from 6.1 billion euros in 2014 (2014 €) and rising to 8.7 billion euros in 2050.
- In the “*REALISTIC*” scenario, we retained that the Horizon 2020 budget will reach €69.3 billion (2014 €) as planned. For Horizon Europe (2021-2027), the European Commission proposed an overall budget of 97.6 billion, from which we retrieved the share of the budget that should finance non-EU countries, and certain parts of the programme, such as Euratom. This led to a budget of 75.4 billion (2014 €). After Horizon Europe (2028-2050), we assumed constant financial support by the EU R&I Programmes per unit of EU GDP, starting from 11.2 billion Euros in 2028, and rising to 15.5 billion Euros in 2050.
- In the “*OPTIMISTIC*” scenario, the Horizon 2020 budget reaches 69.3 billion Euros as in the “*REALISTIC*” scenario. For Horizon Europe (2021-2027), we this time assumed that the budget proposed by the European Commission through increase of 20%, reached almost 120 billion (current euros), i.e. 90.4 billion 2014 euros adjusted to the precise perimeter used with NEMESIS. After Horizon Europe (2028-2050), we also retained a constant financial support by the EU R&I Programmes per unit of EU GDP, starting from 13.6 billion euros in 2028, and rising to 18.6 billion euros in 2050.

Concerning the financing of the EU R&I programmes, in the “*REALISTIC*” and “*OPTIMISTIC*” scenarios, the increase of the EU support, compared to the reference, was financed by the EU member states in proportion to their financial contribution to the EU budget, with an equivalent reduction of their national public investments (excluding research activities).

Then, for all three scenarios:

- The split between “*Basic*” and “*Applied*” research was based on CORDIS²¹ data, with 35% for “*Basic*” research and 65% for “*Applied*” research;
- The national allocation was the same as the allocation of H2020 between 2014 to 2016, with the exclusion the United Kingdom from the calculation after 2020;
- The Sectorial allocation of the funds supporting “*Applied*” research was distributed to the sectors following the grand-fathering principle;
- For the “*Medium*” case, the leverage effect of EU funding was supposed to equal 0.15 (each Euro of EU subsidy leads to 1.15 Euro of R&D investment) against 0.1 for national support in the case of “*Applied*” research and null for “*Basic*” research, whatever the level of the intervention. For the “*Low*” case, the leverage on “*Applied*” research was reduced to 0.1, and it was symmetrically increased to 0.2 for the “*High*” case.
- For the “*Medium*” case, the EU Added-Value of the R&I programmes was assumed, based on the literature (see chapter 6) at 15%: EU research performs 15% better than national research. This was set at 20% for the “*High*” case, and at 10% for the “*Low*” case.

²¹The Commission website registers the results from EU-funded projects from 1990. See <https://cordis.europa.eu/projects/en>

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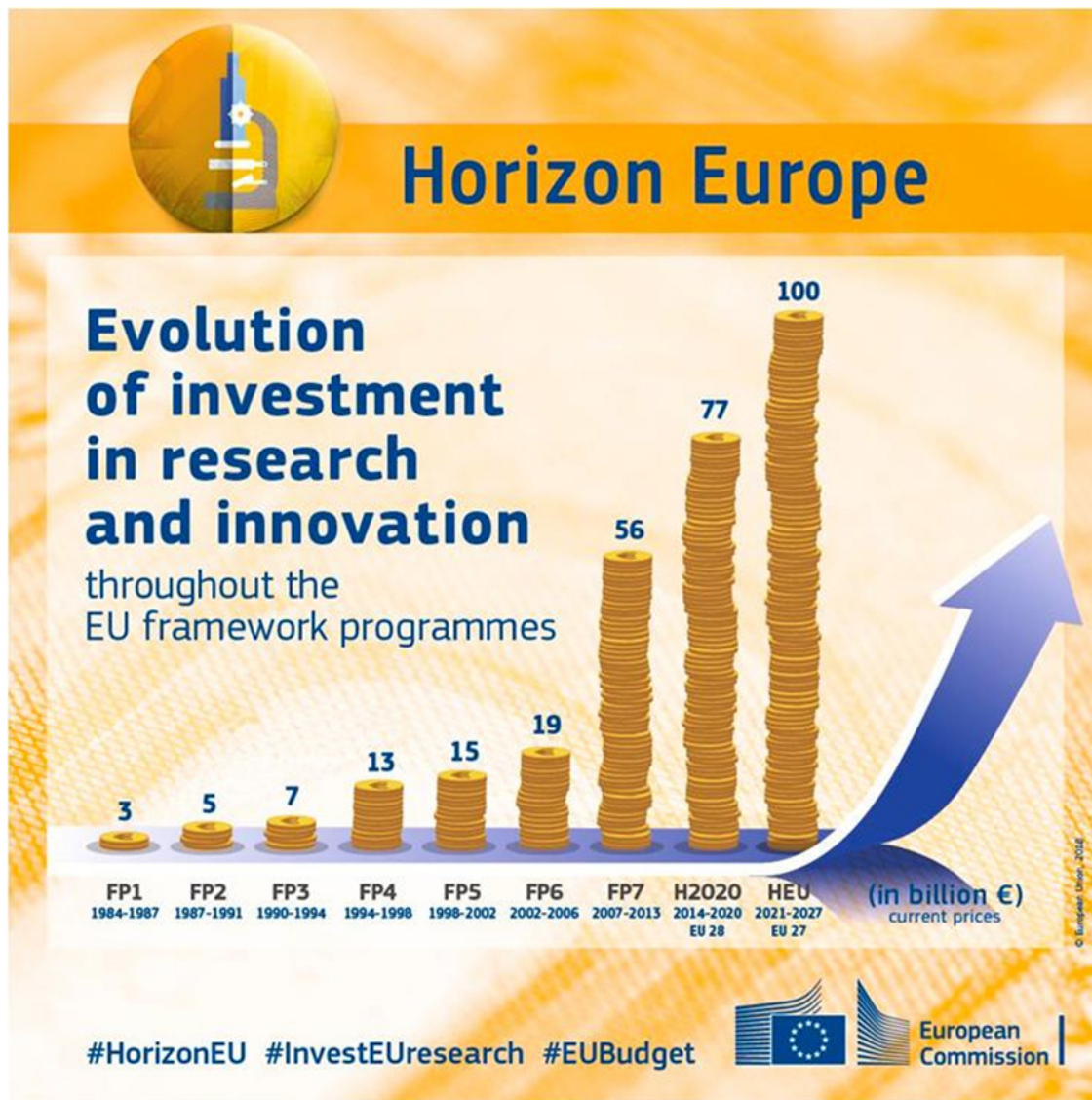
Table 7.3.8 – Assumptions used for implementing the commitment 6 in NEMESIS

	Reference scenario	Low		Medium		High	
		Realistic	Optimistic	Realistic	Optimistic	Realistic	Optimistic
H2020 funding 2014-2020		69.3 billion	69.3 billion	69.3 billion	69.3 billion	69.3 billion	69.3 billion
Horizon Europe 2021-2027*	Indexed on EU GDP growth (from €6.1 bn in 2014)	75.4 billion	90.4 billion	75.4 billion	90.4 billion	75.4 billion	90.4 billion
Post Horizon Europe 2028 to 2050*		Indexed on EU GDP growth (from 11.4 bn in 2028)	Indexed on EU GDP growth (from 13.6 bn in 2028)	Indexed on EU GDP growth (from 11.4 bn in 2028)	Indexed on EU GDP growth (from 13.6 bn in 2028)	Indexed on EU GDP growth (from 11.4 bn in 2028)	Indexed on EU GDP growth (from 13.6 bn in 2028)
Allocation of FP funding to EU MS	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016	H2020 observed data for 2014 to 2016
Allocation of FP funding to basic and applied research	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%
Allocation of FP applied research funding to sectors within MS	Grand-fathering principle	Grand-fathering principle	Grand-fathering principle	Grand-fathering principle	Grand-fathering principle	Grand-fathering principle	Grand-fathering principle
Leverage effect of EU funding for applied research	0.15	0.1	0.1	0.15	0.15	0.2	0.2
Leverage effect EU funding for applied research	0	0	0	0	0	0.1	0.1
Leverage effect of national funding for applied research	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Leverage effect of national funding basic research	0	0	0	0	0	0	0
Economic performance for R&D resulting from EC funding	15% better than national	10% better than national	10% better than national	15% better than national	15% better than national	20% better than national	20% better than national

*: UK excluded

On figure 7.3.1 we see that the EU FP will experience a steep increase in nominal value from 3 billion for FP1, that will reach 100 billion foreseen in the next programme (an increase of 23 billion for Horizon Europe compared to H2020), following a sharp increase between FP6 to FP7 (from 19 to 56 billion).

Figure 7.3.1 – Evolution of the budget of EU R&I framework programmes from FP1



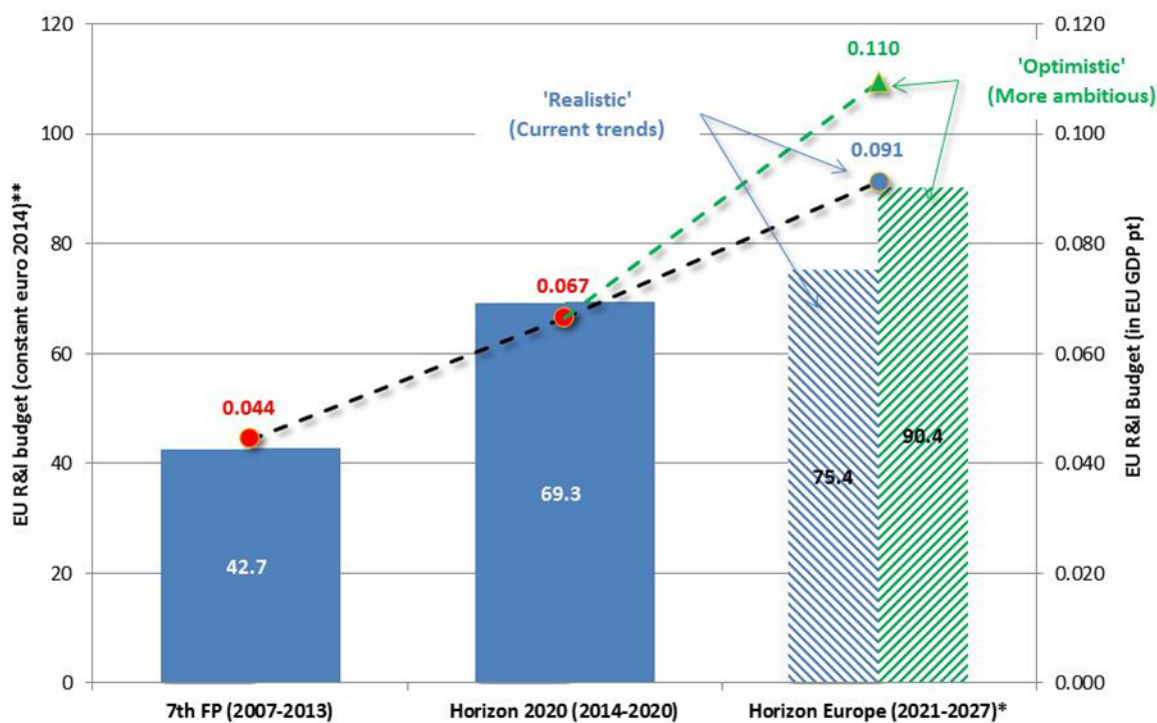
Source: European Commission website

To analyze the current trends more precisely in constant 2014 euros, using the budget outline used to implement the FP in NEMESIS, the increase from Horizon 2020 to Horizon Europe is only 6.1

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billion (In the case of the “*Realistic*” scenario based on the official budget of the Commission under consideration), which is far inferior to the increase represented by the passage from FP7 to Horizon 2020: +27.4 billion. The increase nevertheless remains substantial even though Brexit reduces the budget by about 15% representing the lost UK contribution, and we see that in % of EU GDP the effort actually increases, passing from 0.067% of EU28 GDP for Horizon 2020, to 0.091% of EU27 GDP for Horizon Europe. It is therefore quite comparable to the progress that has represented the passage from FP7 to Horizon 2020 in the figure 7.3.2.

Figure 7.3.2 – Size of EU R&I Programmes in the “*Realistic*” and “*Optimistic*” scenarios (2014 Euros)



*: UK excluded from 2020

** : Budget excluded support to non EU countries

Finally we must underline that the 100 billion euros budgeted for Horizon Europe received a provisional agreement in March 2019²², and that the 20% increase in the budget considered in the more ambitious scenario has little chance of being accepted.

²²see: http://europa.eu/rapid/press-release_IP-19-1676_en.htm

ESI funds for research and innovation- Commitments 24 and 25 The integration of commitments 24/25 in the NEMESIS model follows a relatively similar approach to that of commitment 6. The first quantitative element to define was the budget of the European Structural and Investment Funds (ESIF) used to support R&I objectives, for the three scenarios: “*REFERENCE*”, “*REALISTIC*” and “*OPTIMISTIC*”:

- For the reference scenario, like in the 2007-2013 multiannual financial framework, the overall budget of ESIF funds for R&I was about 51.6 billion Euros (in current prices). We estimated the support for year 2013 at 7.8 billion (in constant 2014 euros). After 2013, we assumed an increase of the ESIF budget to R&I proportional to EU GDP, reaching 12.8 billion constant euros in 2050. The cumulative support from 2014 to 2050, therefore amounts to 374.6 billion constant euros in the reference scenario.
- For the “*REALISTIC*” scenario during 2014-2020 period, we used the official data for planned financing under the different ESI Funds. Table 7.3.9 summarizes the financing at EU and national level and shows that the ESIF budget for R&I reaches 44.1 billion (current euro) at EU level. Among the different funds covered by the dataset, only two funds, the European Rural Development Fund (ERDF) and the European Agricultural Fund for Rural Development (EAFRD), support R&I investments, with almost 95% coming from ERDF (44.1 billion) and the remaining from EAFRD (2.5 billion). *De facto*, the ESIF budget for R&I between 2014 and 2020 is lower than between 2007 and 2013. Consequently the “*REALISTIC*” scenario exhibits a decrease in the ESIF supports for R&I between 2014 and 2020, in comparison with the reference scenario (see table 7.3.10). We estimated this budget deviation at -15.8 billion over the period. After 2020, despite the budget proposal of the European Commission for the 2021-2027 multiannual financial framework, that foresees a constant budget for the ERDF (200 billion), we assumed, in the “*REALISTIC*” scenario, that the share of the ERDF budget to finance R&D investments will grow to close the gap with the reference scenario in 2027. This leads to a share of funds to support R&I investments of 20% for 2021-2027, compared with only 15% for 2014-2020. This assumption reflects the aim of commitment 24, to increase the share of ESIF devoted to R&I. From 2027, the ESIF budgets for R&I grow, by assumption, at the same rate as EU GDP, with amounts identical to the reference scenario. Finally, the difference for the whole 2014-2050 period for the cumulative ESIF budget for R&I is -23.6 billion constant Euros in the “*REALISTIC*” scenario, compared to the reference scenario.

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- For the “*OPTIMISTIC*” scenario, the 2014-2020 period used the same official data as the “*REALISTIC*” scenario. After 2020, instead of an increase of the share of ESI funds for R&I from 15% to 20%, in the “*REALISTIC*” scenario this share rises to 25% for the period 2021-2027. After 2027, this budget is again supposed to continue to grow with the EU GDP. Therefore in the “*Optimistic*” scenario, the cumulative R&I investments supported by ESI funds are almost the same as in the reference scenario for the whole 2014-2050 period, with +5.5 billion constant euros in the “*Optimistic*” scenario. The initial decrease that occurs between 2014-2020, is therefore fully compensated between 2021 and 2050 in this more ambitious scenario.

Table 7.3.9 – Summary of ESIF finance planned by Member state (2014-2020)

Million current €	All ESI Funds* (2014-2020)				ERDF Fund (2014-2020)				EAFRD Fund (2014-2020)				Share of all ESI Funds* (2014-2020)**	
	Total		R&I		Total		R&I		Total		R&I		Total	R&I
	EU amount	Total	EU amount	Total	EU amount	Total	EU amount	Total	EU amount	Total	EU amount	Total	EU amount	EU amount
Austria	4923	10650	277	810	536	2082	206	889	3938	7698	71	141	1.0%	0.70%
Belgium	2742	6089	294	714	953	2331	278	686	643	1326	16	28	0.60%	0.70%
Bulgaria	9978	11728	541	634	3585	4179	494	582	2367	2912	46	53	2.20%	1.30%
Cyprus	917	1170	72	85	300	353	70	82	132	243	2	3	0.20%	0.20%
Czech Republic	23885	33402	2498	4305	1941	1810	2421	4150	2308	3771	77	155	5.30%	5.90%
Germany	27935	44753	4038	6427	10774	17756	3819	6119	9446	14140	219	308	6.20%	9.60%
Denmark	647	2265	104	202	207	399	88	169	919	1187	17	33	0.30%	0.20%
Estonia	4424	5966	660	1106	1657	2573	636	1077	823	994	24	29	1.00%	1.60%
Spain	39791	56103	5252	7939	20565	29108	4961	7535	8297	12311	291	404	8.80%	12.40%
Finland	3765	8435	391	813	792	1584	309	616	2380	5674	82	194	0.80%	0.90%
France	26902	45675	1890	3783	8426	18071	1680	3454	16889	16889	231	329	6.00%	4.50%
Greece	21382	26682	1109	1411	8609	10973	939	1201	4718	5710	170	210	4.70%	2.80%
Croatia	10727	12649	690	812	4322	5084	665	782	2026	2383	26	30	2.40%	1.60%
Hungary	25014	29650	2232	2826	10757	12579	2149	2529	3431	4177	83	97	5.60%	5.30%
Ireland	3362	6140	181	354	411	822	142	284	2191	3922	39	70	0.70%	0.40%
Italy	44656	78108	4202	6985	21661	34219	3786	6129	10444	20913	416	857	9.90%	10.00%
Lithuania	8386	9947	702	828	3501	4119	679	799	1613	1978	23	27	1.90%	1.70%
Luxembourg	140	456	9	23	20	48	9	23	101	388	0	0	0.00%	0.00%
Latvia	5634	6907	488	580	2401	2825	468	550	1076	1532	21	30	1.30%	1.20%
Malta	828	1024	73	92	384	477	58	72	97	130	16	20	0.20%	0.20%
The Netherlands	1687	3745	364	984	510	1372	335	931	765	1214	29	53	0.40%	0.80%
Poland	86112	104921	8372	9946	40214	47506	8281	9803	8898	16612	91	143	16.10%	23.30%
Portugal	25482	31982	2387	3566	10777	14820	2329	3499	4059	4733	58	66	5.70%	7.10%
Romania	30883	37590	1087	1292	10726	13280	998	1189	8128	9931	88	104	6.90%	8.30%
Sweden	3627	8053	342	742	935	1896	255	522	1764	4412	87	220	0.80%	1.80%
Slovenia	3931	4958	500	628	1417	1824	476	595	338	1107	24	31	0.90%	1.10%
Slovakia	15287	19559	1799	2993	7292	9740	1760	2940	1660	2099	39	53	3.40%	4.30%
United-Kingdom	11471	26799	1657	2843	5857	10357	1432	2541	5195	8775	224	302	3.70%	5.90%
Territorial Cooper	9801	13088	1667	2709	9335	12540	1867	2709	0	0	0	0	--	--
European Union	480297	646473	44075	66225	199044	281028	41670	62240	99348	150840	2505	3996	100.00%	113.80%

Source: European Commission, <https://cohesiondata.ec.europa.eu/EU-Level/ESIF-2014-2020-FINANCES-PLANNED-DETAILS/e4v6-qrrq>, extraction 5th July 2018

*: Including CF, EAFRD, EMFF, ERDF, ESF, IPAE and YIE funds.

** : Territorial Cooperation excluded

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Table 7.3.10 – Summary of the assumptions used to implement the commitments C24/25 in the NEMESIS model

		Reference scenario	Low		Medium		High	
			Realistic	Optimistic	Realistic	Optimistic	Realistic	Optimistic
European structural and investment funds devoted to R&I (constant euro 2014)*	2014-2020		€42.7 billion (based on planned data)**	€42.7 billion (based on planned data)**	€42.7 billion (based on planned data)**	€42.7 billion (based on planned data)**	€42.7 billion (based on planned data)**	€42.7 billion (based on planned data)**
	2021-2027	Indexed on EU GDP growth (from €7.9 bn in 2014)	Adjustment to reference scenario in 2027 (i.e. €54.4 billion)	Increase share of R&I investments in ESIF, from 15% to 25%*** (i.e. €66.7 billion)	Adjustment to reference scenario in 2027 (i.e. €54.4 billion)	Increase share of R&I investments in ESIF, from 15% to 25%*** (i.e. €66.7 billion)	Adjustment to reference scenario in 2027 (i.e. €54.4 billion)	Increase share of R&I investments in ESIF, from 15% to 25%*** (i.e. €66.7 billion)
	2028-2050		Indexed on EU GDP growth (from €9.4 bn in 2028)	Indexed on EU GDP growth (from €10 bn in 2028)	Indexed on EU GDP growth (from €9.4 bn in 2028)	Indexed on EU GDP growth (from €10 bn in 2028)	Indexed on EU GDP growth (from €9.4 bn in 2028)	Indexed on EU GDP growth (from €10 bn in 2028)
Allocation of R&I ESIF to MS**	Planned data for 2014 to 2020	Planned data for 2014 to 2020	Planned data for 2014 to 2020	Planned data for 2014 to 2020	Planned data for 2014 to 2020	Planned data for 2014 to 2020	Planned data for 2014 to 2020	
Allocation of R&I ESIF to basic and applied research	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	Applied: 65%, Basic: 35%	
Allocation of R&I ESIF applied research funding to sectors within MS	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	Grand-fathering principle (based on Eurostat BERD 2014)	
R&I ESIF direct crowding-in factor for applied research (net additional funding generated)	0.1	0.05	0.05	0.1	0.1	0.15	0.15	
R&I ESIF direct crowding-in factor for basic research (net additional funding generated)	0	0	0	0	0	0	0	
Economic performance for R&D resulting from R&I ESIF funding	As national	As national	As national	7.5% better than national	7.5% better than national	15% better than national	15% better than national	

*: UK excluded from 2021

** : Source: <https://cohesiondata.ec.europa.eu/EU-Level/ESIF-2014-2020-FINANCES-PLANNED-DETAILS/e4v6-qrrq>, extraction July 2018

***: For 2021-2027, estimated share based on European Commission proposal for the next multi-annual financial framework for the period 2021-2027 (<https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52018PC0372&from=EN>)

Finally, we must underline that these FP and ESI funds are important elements of convergence between the different member states of the EU. Therefore, while there will be no tendency to increase the share of the FP for the weakest innovation systems in the EU under FP7 and beginning of H2020; nevertheless in proportion of GDP, generally the FP provides more benefit generally more to countries with the weaker systems, in the east and south of the European Union²³. This remains limited and should

²³For the commitment 6, the GDP gains in 2040 under the current trend scenario range actually from 0.98% in Slovenia, 0.85% in Finland and 0.72% in Estonia, to 0.07% in Czech Republic, and 0.04% in Slovakia and Poland. See Le Mouél et al. (2018, [207]), or follow this link for the full model results: <http://www.i3u-innovationunion.eu/wordpress/wp->

be increased in the future. In the case of ESI funds for R&I, they are among the most inclusive actions of the Innovation Union, as they focus precisely on developing countries that lag behind as far as innovation systems are concerned. Unfortunately, the overall budget of ESI funds for R&I will not grow under current trends, and very little progress in convergence should be expected from the evolution in European funds over the next decade²⁴.

7.3.1.4 Implementation of the group 4 commitments: “Action to market”

This last group of commitments includes the commitments aiming at fostering innovation from market interactions or the introduction of new regulations and monitoring. It includes commitments C19-1, “Creative industries”, and C19-2, “EU design leadership board”.

Commitment 19-1- “Creative industries” is aimed at provoking structural change in order to improve the performance of European creative industries, and commitment 19-2 - “EU design leadership board” is based on the necessity to better understand the role of design as a driver for innovation and to improve the design infrastructure and services.

Direct impact assessments for these two commitments was made by the ULB, and the results are available in Anic *et al.* (2018, [14]).

They both act in the NEMESIS model (see table 7.3.11) because of their impact on R&D investments by private firms.

content/uploads/2018/09/I3U-C6-NEMESIS-RESULTS.xlsm

²⁴For the commitments 24/25, the GDP gains in 2040 under the current trend scenario range from 0.99% in Bulgaria, 0.77% in Lithuania and 0.66% in Latvia, to -0.04% in SWEDEN, -0.03% in Austria, Belgium and Denmark, and -0.14% in Finland. See Le Mouél *et al.* (2018, [207]), or follow this link for the full model results: <http://www.i3u-innovationunion.eu/wordpress/wp-content/uploads/2018/09/I3U-C24-25-NEMESIS-RESULTS.xlsm>

Table 7.3.11 – Modification of NEMESIS model to implement Group 4 commitments

Commitment	WP	Team	Thematic	Entry/mechanisms in NEMESIS
19.1 Creative industries	5	ULB	Action to market	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: j_{cit}^* , with j standing for R&D, ICT and OI.
19.2 EU design leadership board	5	ULB	Action to market	1- Optimal demand of innovation inputs from equations E1 to E3 in table 4.3.2: j_{cit}^* , with j standing for R&D, ICT and OI.

Source: Le Mouël et al. (2019, [206])

In the case of commitment 19.1 that we take as example, the commitment action aims at increasing the impact of creative industries on R&D, productivity, etc... to enhance competitiveness and job creation by EU firms. One action that was undertaken was the creation of a supportive ecosystem (European Creative Industries Alliance Policy Learning Platform - ECIA). The ECIA provided support to some 3,570 SMEs by mentoring, training and cross-border matchmaking. Across the nine projects carried out between 2012 and 2014, the ECIA succeeded in mobilizing at least 45.8 million euros directly or indirectly for the creative industries on top of the 6.75 million euros of EU support for the initiative (ECIA, 2014). Furthermore, CI also have an impact on the performance of other industries and on the activities of their suppliers (see Anic *et al.*, [14], *ibid*, page 18).

The integration of this commitment in NEMESIS therefore has to be made through these channels of impacts, as well as the measurement of the leverage effect that R&D investments in creative industries have on the R&D investments of firms in the other sectors of the economy. An econometric estimation was performed, with as a dependent variable R&D investments by non-creative industries in percentage of GDP, and as an explanatory variable R&D investments by creative industries in percentage of GDP. The data were adapted from EUROSTAT and cover all the EU28 member states for the period 2007 to 2015. This estimation included control variables and the results used for NEMESIS are those for the fixed effect panel data regression model (Table 2.4 in Anic *et al.*, [14], *ibid*, page 18). The value of the parameter estimated is 0.134, with a standard deviation of 0.0839. Using the mean values of the variables at EU level, we could see that in all three scenarios:

- In the “*Medium*” case, one additional Euro of BERD by creative industries increases BERD by non-creative industries by 1.83 Euro, at 2016 prices;
- In the “*Low*” case, taking into account the value of the standard deviation, this marginal effect is equal to 0.69 Euro;
- In the “*High*” case, the marginal effect is equal to 2.98 Euros.

Between 2007 and 2015, the BERD by creative industries increased by 0.025 point of EU GDP, passing from 0.035 to 0.06 pt. Then the following assumptions were used to design the “*Reference*”, the “*Realistic*” and the “*Optimistic*” scenarios:

- In the “*Reference*” scenario, after 2013, it was assumed that the amount of BERD by creative industries grows with the EU GDP, leaving the amount of BERD by creative industries in percentage of the EU GDP constant. For the national allocation, we used the mean share, calculated for the period 2007-2015, for each country of the total BERD by creative industries at EU28 level;
- In the “*Realistic*” scenario, we used the historical data for BERD by creative industries in the different EU countries up to 2015. After 2015 and up to 2027, we assumed that the amount of BERD by creative industries will grow 2.2% per year in volume, leading to an additional increase of 0.015 point of EU GDP in 2027, compared to the level reached in 2015. Then after 2027, the BERD by creative industries was supposed to grow with EU GDP and to stay constant in percentage of EU GDP, like in the reference scenario. The national allocation in the “*Realistic*” scenario is similar to that of “*Reference*” scenario, i.e. it is based on the average share for each country of the total BERD by creative industries at EU28 level, calculated for the period 2007-2015.
- For the “*Optimistic*” scenario, the same methodology as for the “*Realistic*” scenario was used, but the BERD by creative industries was supposed to grow twice as fast between 2015 and 2027, with an increase of 0.03 point of EU GDP in 2027, compared to the level reached in 2015.

Table 7.3.12 displays the corresponding figures in absolute levels and in billion constant Euros, for the different scenarios in average amount per year.

Table 7.3.12 – Assumptions used for implementing the commitment 19.1 in NEMESIS

		Reference scenario	Low		Medium		High	
			Realistic	Optimistic	Realistic	Optimistic	Realistic	Optimistic
Business expenditures on R&D (BERD) by the Creative Industries (average per year, in billion constant euro 2014)	2014-2015	7	8.2					
	2016-2020	7.4	9.1	9.6	9.1	9.6	9.1	9.6
	2021-2027	8.1	10.4	12.2	10.4	12.2	10.4	12.2
	2028-2050	10.1	13.3	16.4	13.3	16.4	13.3	16.4
	2014-2050	9.3	11.5	13.3	11.5	13.3	11.5	13.3
Direct leverage effect of the BERD by Creative Industries on other private R&D investments**		€ 1.83	€ 0.69	€ 0.69	€ 1.83	€ 1.83	€ 2.98	€ 2.98

Source: Eurostat, Anic et al. (2018, [14]) and authors' calculation

** : Euro invested in R&D by private sector for each euro invested by the Creative Industries in R&D

Commitment 19-1, as well as commitment 19-2, belong to the group of seven commitments that was identified by the Conceptual model of the European Union Innovation systems as affecting more positively the weaker innovation systems than the strongly developed ones, that are expected to favor convergence between EU countries. Based on the development of creative industries in the different countries, the results of the NEMESIS model are nevertheless more mitigated in the case of commitment 19-1, while the impacts of commitment 19-2 are very weak because of the lack of a robust design infrastructure in many countries, and the fall in the number of new designs observed these last years²⁵.

7.3.1.5 Taking into account overlapping between individual commitments when assessing them in groups or as a whole

Finally, when assessing the impacts of the commitments in groups or as whole using NEMESIS, to get a global picture of the socioeconomic benefits that progress of the Innovation Union could bring in the future, it is necessary to take into account any existing overlapping between their individual actions, and avoid double-counting of impacts. We now analyze these different aspects.

²⁵For commitment 19-1, the GDP gains in 2040 are therefore, under the current trend scenario, from 2.05% in Estonia, 0.78% in Ireland and 0.74% in Malta, to 0.05% in Slovakia, -0.04% in Hungary, and -0.05% in Czech Republic. See Le Mouël et al. (2018, [207]), or follow this link for the full model results: <http://www.i3u-innovationunion.eu/wordpress/wp-content/uploads/2018/09/I3U-C19-1-NEMESIS-RESULTS.xlsm>

Analysis of overlapping between Group 1 commitments - “Human capital” For the commitments of group 1- “Human capital”, the actions supported by the four commitments are complementary, and there is no reason to suppose, *a priori*, that they overlap. They respectively promote, commitment 2.2, the private/public partnerships, commitment 3, the development of e-skills, commitment 4.2, the mobility of EU researchers inside Europe, and commitment 30, the attractiveness of Europe for researchers from third countries. Their primary objectives appear quite orthogonal and though they do not overlap, on the contrary it may be expected that there are synergies between them. Therefore, if there is any potential overlapping between the four commitments for “human capital” it would concern, rather than their individual objectives, any effects on the productivity of public research, as measured by Castellacci *et al.* (2017, [55]):

Commitment 4.2, “ERA research mobility”, has an impact through a variable measuring the share of researchers currently employed in country other than their country of citizenship. Data were only available for the year 2012 for each EU-28 country, and therefore only cross sectional analysis, on a small sample, was possible. In any case, the elasticity coefficient estimated econometrically was significant at the 1% level.

Commitment 30, “Foreign talents”. The impact was measured using a variable measuring the importance of “Researchers and scientists that are attracted to your country” (Survey responses reflect the perceptions of global business executives, on a 1-10 scale – degree of agreement). The data cover the period 2010 to 2016 and are for each EU-28 country. The time dimension is quite short, 7 years, but it allowed for panel estimates, that are *a priori* more robust, for describing the effect of this commitment, than the cross-sectional analysis used for commitment 4.2. But the estimated parameter, although positive, was only weakly significant.

For these two first commitments, the effects measured are therefore only tentative, and must be used with prudence.

In the case of commitment 30, the semi-ordinal variable used to “reflect” the commitment (survey response “reflecting the perceptions of global business executives”) is indirect and poor. Its definition is also close to the variable “MOBILITY” used to assess the impact of commitment 4.2, and part of the effect measured by the variable “ATTRACT_RD”, that may also capture some of the effects of the variable “MOBILITY” used for commitment 4.2 and conversely. So, to avoid over-optimistic results when assessing the effects of all the Group 1 commitments, we took the decision not to include commitment 4.2.

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Commitment 2.2, “*Knowledge alliances for skill gaps*”. The only variable available to capture the effect of this commitment, is also semi-ordinal (“*Perceptions of global business executives on a 1 to 10 scale*”) and far from a direct quantitative measure of the importance of knowledge transfers between private/public, like, for example, the number of joint scientific publications, or the number and the duration of collaborations in terms of total man-months, or total budget spent on scientific collaborations, etc. We decided to keep this commitment in the model for the joint assessment of group 1’s commitments, but the data necessary for the direct assessment of the effects of this commitment calls for strong improvements in future assessments.

Commitment 3, “*An integrated framework for e-skills*”, also has numerous limitations. The most important is that commitment 3 has a broader scope and does not only improve e-skill competencies in public research organizations. It aims, as a matter of priority, at promoting the development of e-skills necessary for both public organizations and private companies, as well as for both innovation and production activities. Castellacci *et al.* (2017, *ibid*) provide an additional econometric study, based on new e-skill data that distinguishes three e-skill categories (see Castellacci *et al.*, *ibid*, page 70): developers, practitioners and users, for all EU NUTS-2 regions and NACE 1-digit industry levels. The study notably shows for European regions, sectors and countries, a positive and significant relationship between the three types of e-skills, on the one hand, on innovation output (measured by patents per capita) and labor productivity, on the other hand. Unfortunately, the results of this study for private companies could not be used for the I3U project. For this commitment, both the level of the data used (“*Proportion of workers with ICT user skills, in % of total employment*”) and their scope (public organizations only) are too narrow to describe the effects of the commitments in the NEMESIS model adequately. Nevertheless, commitment 3 was retained for the joint assessment using NEMESIS of the Group 1- “Human capital” commitments, but its contribution to the overall impacts is certainly under-evaluated as explained above.

In summary, for robustness reasons, and to avoid any potential overlapping between commitments 3.0 and 4.2, the latter was excluded from the joint assessment of Group 1 commitments using NEMESIS, and only commitments 2.2, 3 and 3.0 were integrated in the assessment.

Analysis of overlapping between Group 2 commitments: “*Access to finance*” For the commitments of group 2- “*Access to finance*”, that all aim at increasing investment in R&D&I by private firms by facilitating the financing of firms’ innovation, and notably the access to finance for

SMEs, a lot overlapping is to be expected. These potential overlappings are at the same time difficult to control insomuch as most of the available data, used for the direct impact assessment of the individual commitments, are confidential or only available at an aggregate level and in an anonymous form. Furthermore, there is no possibility to make checks, for example, whether the same financing source is accounted for twice, in different data sources, and therefore to proceed to the necessary correction of the data. For example, in the case of the European Investment Bank (EIB) funds that are the “*Risk Sharing Finance Facility*” and today the “*InnovFin*” instrument, the marginal effect estimated by Cincera and Santos (2018, [59]) of 3.55 euro additional corporate R&D investment for each euro received by the EIB, should reflect the strong development of the EuVECA funds. We should therefore expect that commitments 10 and 11 strongly overlap. For commitment 12, the proxy used by the authors to assess the commitment, the amount of BERD financed by abroad, is also strongly influenced by the fast development of venture capital, that is to a large extent cross-border. Thus, commitment 12 should overlap strongly with 11, and also with 10.

When jointly assessing these commitments that have a significant risk of overlapping, we therefore decided:

- For commitment 10, to retain only the amount of the loans from the EIB, and not take into account the estimated leverage effect (of 3.55 Euros);
- To abandon commitment 12 as it is impossible to evaluate to what extent the “*BERD financed by abroad*” concerns EuVECA funds and funds leveraged by the EIB;
- To keep commitment 11 as it is, that is to say with the same integration methodology in NEMESIS like in Le Mouël *et al.* (2019, [207]);
- Finally, for the remaining commitment 13, there is no reason to fear possible overlapping with the three other commitments, especially because we assumed a much more lower direct leverage effect on private R&D investment than originally estimated by Cincera and Santos (2018, *ibid*).

To sum up, commitments 11 and 13 are implemented in the same way as their direct impact assessments by Cincera and Santos (2018, *ibid*), whereas for commitment 10, we considered that there is no longer an effect of EIB funds on private R&D investment, for the assessment by group. Commitment 12 is left out because of high potential overlapping with commitment 11.

Analysis of overlapping between Group 3 commitments: “EU funds” For this third group of commitments that includes commitment C6- “EU R&I FP” and C24/25- “Improve/increase ESIF budget for R&I”, that rely on different EU funding mechanisms, we cannot see any potential overlapping.

Analysis of overlapping between Group 4 commitments: “Action to market” Concerning the last group of commitments, Group 4- “Action to market”, that includes commitments C19.1 - “Creative industries”, and C19.2, “EU design leadership board”, the sharp increase observed in the number of registered community designs from 2006 to 2013, should principally reflect the strong development of creative industries during that period. Commitment C19.2 is likely to overlap with commitment C19.1, at least according to the methodology used for their direct impact assessment and for implementing them in NEMESIS. Consequently, to jointly assess these two commitments in group 4 with NEMESIS, we removed commitment C19.2 that anyway has, according to the implementation methodology presented in Le Mouël *et al.* (2019, *ibid*), a very limited impact.

Analysis of overlapping between the four groups of commitments Finally, when assessing the Innovation Union commitments as a whole, we must take into account not only any potential overlapping existing inside each group of commitments, but also that between the four groups.

The most obvious overlapping that can be identified between the four groups of commitments are between commitment 10 of group 2- “Put in place EU-level financial instruments to attract private finance”, and commitment 6 of group 3- “EU Research and Innovation Programmes”. The support for InnovFin by the European Commission is actually part of the Horizon 2020 budget. To avoid accounting for the EU budget allocated to InnovFin twice, it is necessary therefore to subtract around 1 billion Euros per year from the leverage effect of the InnovFin instrument, representing the share of the EU R&I budget allocated to the InnovFin instrument.

Finally, attentive readers could question the potential overlapping between commitments in Group 1 - “Human Capital” and commitment 6. For instance, this could be the case with the “Marie Skłodowska-Curie Action” that is a part of the first Pillar “Excellent Science” of the Horizon 2020 Programme and commitment 4.2 – “ERA - Research Mobility”. In any case, commitment 4.2 is already excluded from the assessment of Innovation as a whole as it overlaps with commitment 2.2. Similarly, the “Future and Emerging Technologies” programme of Horizon 2020 could also overlap with commitment 2.2 – “Knowledge alliances for skill gaps”, through active partnerships between private research entities and

public ones. But the way the action of this commitment is introduced in the model, with a positive influence on the productivity of public research organizations in the different member states, is much broader than the scope of the FP, even if for some of the countries with weaker innovation systems, the FP can represent a large part of the overall public R&D performed. We can nevertheless expect that this kind of potential overlapping of the commitments introduced in the model with the FP will remain limited, and should only cause a limited over-estimation of the socioeconomic impacts of the Innovation Union commitments “*as a whole*”.

So, when assessing the Innovation Union commitments as a whole using NEMESIS commitment 4.2- “*ERA – Research mobility*”, 12- “*Access to finance – Matching*” and 19.2- “*EU design leadership board*” are left aside. For the commitment 10- “*RSFF/InnovFin*”, we consider that there is no leverage effect of EIB funds on private R&D investment, and that the financial contribution of the European Commission to from the FP to this instrument is removed.

7.3.2 The socioeconomic impacts of the Innovation Union

In this section, we present a synthesis of the main socioeconomic impacts of the Innovation Union commitments that were estimated using the NEMESIS model. First, we focus the presentation on the evaluation of the socioeconomic impacts of the Innovation Union as a whole, at both EU-27 and national levels. We notably provide an estimation of employment and GDP gains that the progress observed in the implementation of the Innovation Union could generate in the future years, up to 2050. By comparing the impacts in the different countries, we will also investigate whether “globally”, the Innovation Union, under current trends, favors convergence between the member states or, on the contrary, is a factor of divergence.

The Conceptual model of the European Innovation systems developed by Maastricht University for the I3U project, characterized four different clusters of national innovation systems (Verspagen *et al.*, 2017b, [329]) to which the different EU countries belong, with:

1. *Strongly developed* innovation systems: Austria, Belgium, Denmark, Finland, Germany, the Netherlands, Slovenia, Sweden, and the United Kingdom;
2. *Publicly policy-led* innovation systems: France, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta and Portugal;
3. *Developing* innovation systems: Bulgaria, Croatia, Cyprus, Czech Republic, Hungary, Romania,

Slovakia and Spain;

4. *Lagging behind* innovation systems: Estonia, Greece and Poland.

Then, when looking at the wide heterogeneity in the innovation systems and projecting the Innovation Union 34 commitments into the conceptual model, two main groups of commitments could be distinguished; depending on whether there is a potential for greater divergence between the “*strongly developed*” innovation systems in Europe and the “*developing*” or “*lagging behind*” innovation systems, or whether, on the other hand, their action more positively affects the weaker innovation systems than the strongly developed ones. For the thirteen commitments that could be “quantified” using the NEMESIS model we have:

1. Eight commitments that may increase divergence between the stronger and the weaker innovation systems: The commitments in Group 1- “*Human capital*” (2.2, 3, 4.2, and 30), one commitment in Group 2- “*EU funds*” (6), and three of the four commitments in Group 3- “*Access to finance*” (10, 11 and 12);
2. Five commitments with actions that tend to favor convergence of the “*developing*” and “*lagging behind*” innovation systems: Two commitments of Group 2- “*EU funds*” (24 and 25), one commitment in Group 3- “*Access to finance*” (13), and the two commitments in Group 4- “*Action to market*” (19-1 and 19-2).

Then, in a second step, we will propose an analysis of the action in the model of the individual commitments, and check whether the simulation results confirm this categorization in the terms for convergence/divergence provided by the Conceptual model, therefore providing an indirect validation, or invalidation, of the global analytical approach followed in the I3U project.

7.3.2.1 The evaluation of the Innovation Union as a whole

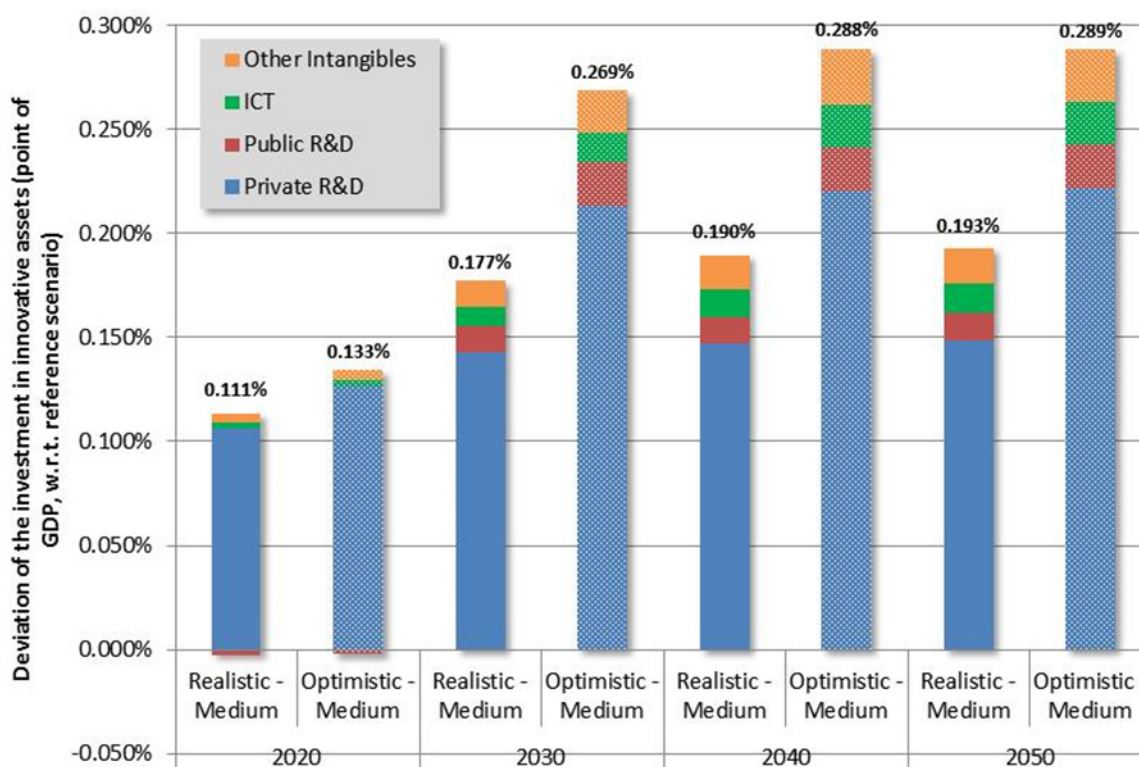
The importance of the pulling effect Before entering in the detail of the results, it is interesting to recall how the commitment act in the NEMESIS model. For the commitments in Group 1- “*Human capital*”, they increase the productivity of public research, and therefore increase the general knowledge externalities from public universities and research institutes towards private firms, that then transform them into process and product innovations. The other three groups of commitments have a direct leverage on R&D investments by private firms. The latter will also provoke knowledge externalities that will spread over firms, sectors and countries.

These increases in R&D investments and in knowledge externalities will also have pulling effects on investments in other innovation assets by private firms. The reasons for this, as analyzed in chapter 5, are that the assets complement each other in the innovation strategy of firms and sectors, and that whenever knowledge spillovers increase, it makes it more profitable for firms to invest in innovations, which simultaneously pulls-up demand for every assets.

These pulling effects are therefore important to understand the simulation results of the model, and put in perspective the impacts that are measured for the different countries.

To illustrate the amplitude of the pulling effects, figure 7.3.3 shows in the “*Realistic*” and “*Optimistic*” scenarios in the “*Medium*” case, how investments in the different innovation assets, in % on the EU GDP, evolve in the model between 2020 and 2050. The first statement is that the pulling effects that investments in private R&D have on the other assets take a long time. They are close to zero in 2020, that is to say six years after the beginning of the simulation (the start year is 2014); then they increase sharply with the important rise in R&D investments provoked by the reinforcement of the commitments action in the model up to 2027.)

Figure 7.3.3 – Change in innovation asset investments in GDP points, compared to the situation in the reference scenario



Source: NEMESIS model

In 2030, after the commitments implementation stopped increasing in the model, the rise of the investment in private R&D is close to its maximum. It has already generated a great number of knowledge externalities that give firms incentives to invest in ICTs and in other intangibles, as innovations become less costly to produce and are more profitable. In that year, private R&D investments increase by about 0.14 GDP point in the “Realistic” scenario, and the pulling effects on ICT and other intangible investments are about 0.009 and 0.013 GDP point respectively²⁶.

Then, in 2040, the rise in private R&D investments nearly stabilizes in GDP points, compared to 2030, as the commitments actions no longer increase after 2027. In any case, the knowledge spillovers continue to grow, and the pulling effects on ICT and other intangible assets in the “Realistic” scenario are now respectively around 0.013 and 0.017 GDP point.

We also see that in 2040, the rise of innovation asset investments in percentage of GDP nearly

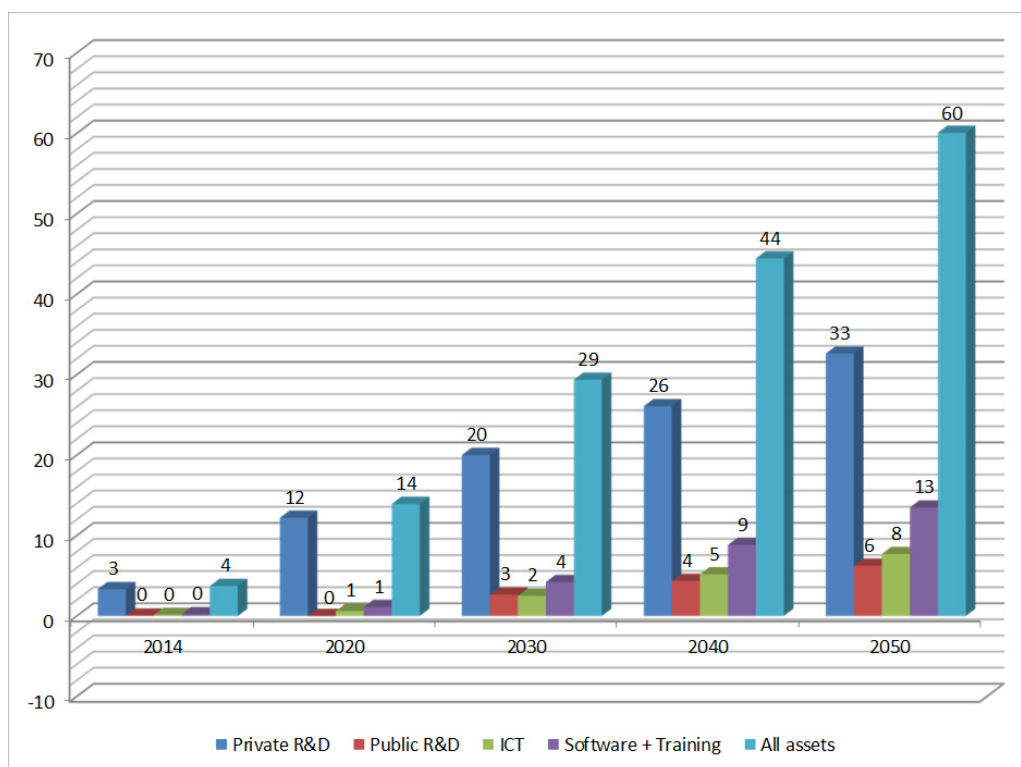
²⁶The rise of public R&D intensity is provoked by the action of the group 2 commitments - “EU funds”.

stabilize (if we compare to the 2050 level), and this can be interpreted as the fact that the macro track of EU economy reaches its new long-run path.

These pulling effects of private R&D investments and R&D knowledge externalities on investments in ICT and other intangibles may appear weak, but all together they represent an additional investment of 20% in innovation assets, that will reinforce the effects of the commitments on innovation and on the EU economy by the same amount.

Finally, by studying the evolution of the levels, rather than the intensities of these different investments, a different picture is produced.

Figure 7.3.4 – Change in innovation asset investments in 2014 constant billion €, difference with the reference scenario

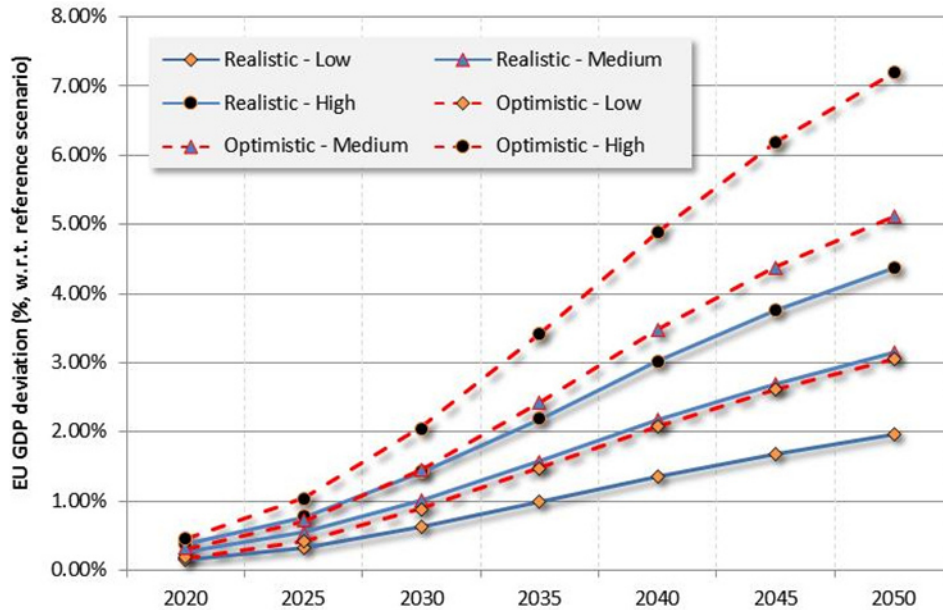


Source: NEMESIS model

Figure 7.3.4 indicates that in 2040, each Euro invested in R&D is accompanied by 0.54 Euros additional investment in R&D, while it is 0.63 Euro in 2030. Measured in this way, the real importance of the pulling effects, provoked by the R&D investments on the other assets, is revealed, as well as the great influence they have on the model's results.

GDP gains and jobs creations at EU-27 level How would the Innovation Union impact European economy and the evolution of GDP?

Figure 7.3.5 – GDP gains in the six scenarios in percentages compared to the reference scenario

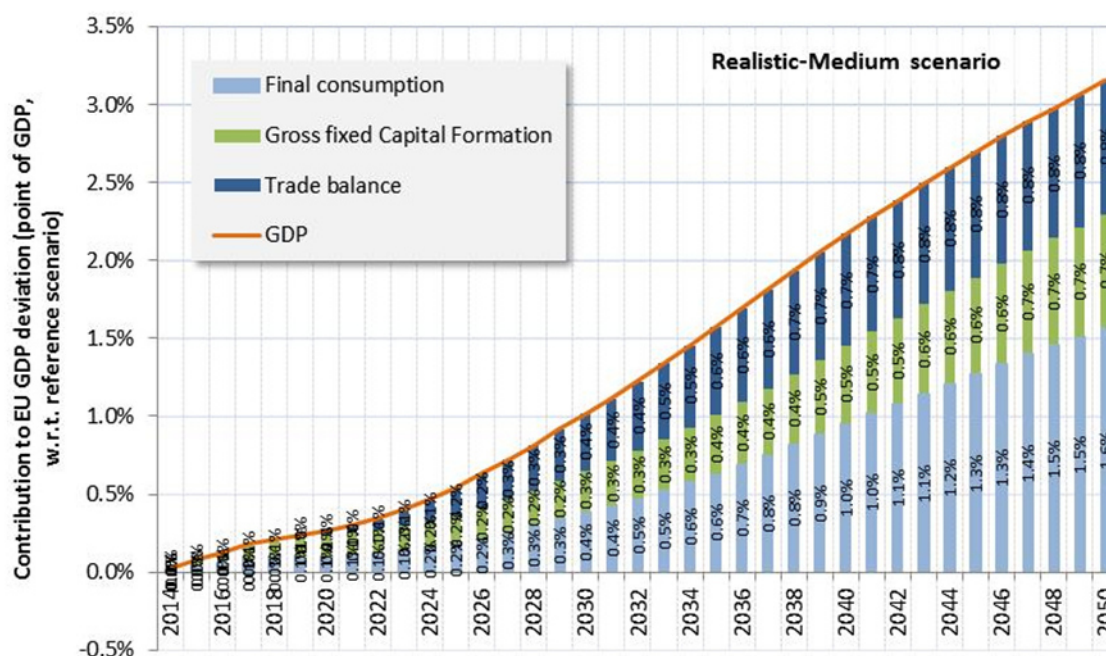


Source: NEMESIS model

Figure 7.3.5 reveals that these could be very substantial. Taking into account the uncertainty surrounding the precise value of the parameters used to show the impact of the commitments in the model, this could reach in 2040 between 1.3% and 3% with a “mean” gain of 2.2% under current trends, and between 2% and 4.9% and a “mean” at 3.5% in a more ambitious scenario. These gains take time to develop because of the very progressive increase in the commitments action in the model, between 2014 and 2030, and the long time lags existing between the initial investment in innovation inputs, the knowledge spillovers, the innovations and finally the positive impacts on economy at large.

Looking more closely at the composition of these changes in the economic activity for the “Medium” case in the “Realistic” scenario, figure 7.3.6 shows that on a global GDP gain of 2.2%, 0.7% would come from the contribution of external balance, 0.5% from investment, and 1% from households’ final consumption.

Figure 7.3.6 – Decomposition of the GDP gains in the “Medium” case in the “Realistic” scenario



Source: NEMESIS model

Projecting these evolutions in the long-run to see to what extent this innovation could modify the EU-27 potential GDP growth rate, table 7.3.13 shows that the Growth rate of the European economy could be very positively impacted, with a mean gain of about 0.1% in the case of the “Realistic” scenario, and of 0.16% for the “Optimistic” one. Taking into account the uncertainty of the exact value of the parameters used, depending on the scenario these gains could fall to only 0.06% in the pessimistic case, or conversely to 0.22%, for the more optimistic one.

Table 7.3.13 – The gains for EU economy growth rate compared to the reference scenario

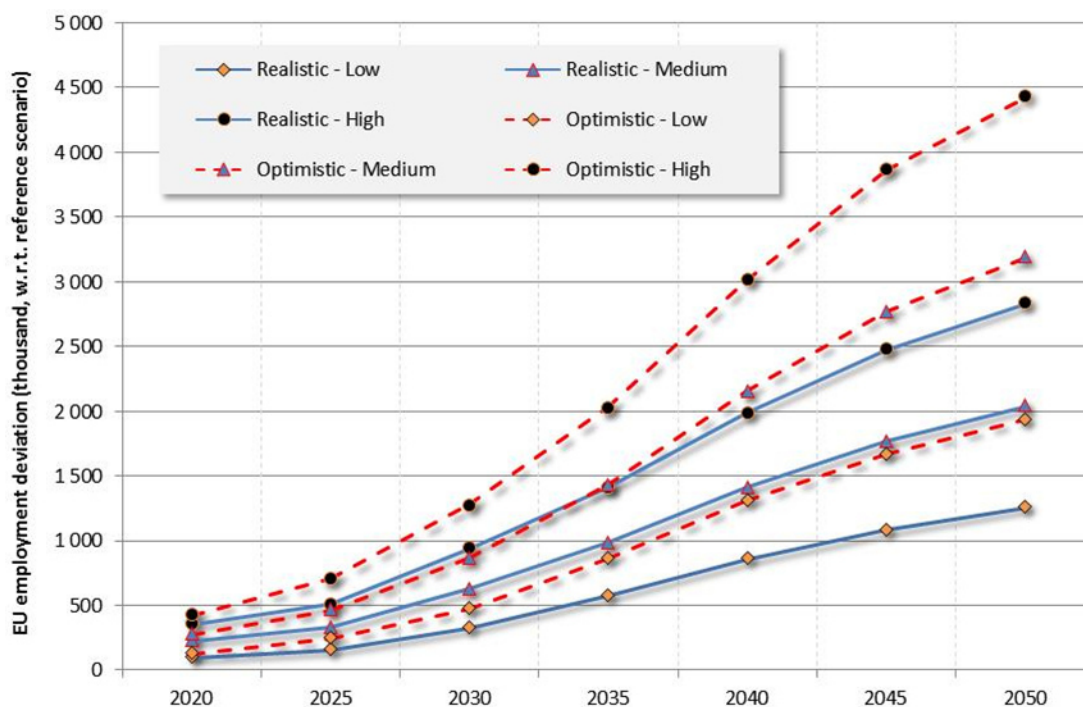
	Long-term annual EU GDP growth rate deviation (point, w.r.t. reference scenario, average 2040-2050)	
	Realistic	Optimistic
Low	0.06%	0.10%
Medium	0.10%	0.16%
High	0.13%	0.22%

Source: NEMESIS model

For employment, the gains calculated by the model (see figure 7.3.7) are also very important, with

the creation in 2040 of between 862 and 1990 thousand jobs, with a mean at 1413, for the “*Realistic*” scenario, and between 1313 and 3015 thousand new jobs, with mean in 2159, for the “*Optimistic*” one. In 2050 it represents between 0.5% and 1.2% of total EU-27 employment, depending the case considered.

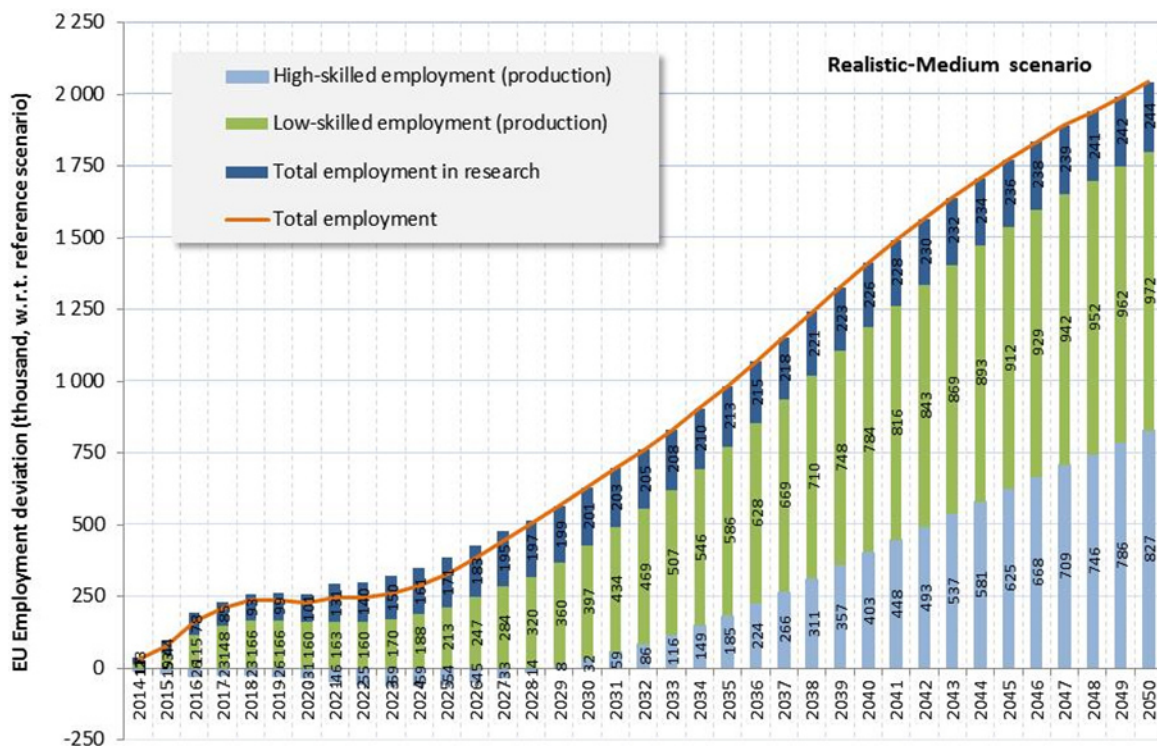
Figure 7.3.7 – The new job creations by the innovation Union in EU-27, compared to the reference scenario in thousands



Source: NEMESIS model

In terms of the job categories that are created, figure 7.3.8 indicates, for the medium case in the “*Realistic*” scenario, that in 2040 of the 1.4 new jobs created, 403 thousand would correspond to high-skilled jobs, 784 thousand to low-skilled ones, and 226 to the employment of doctors, engineers and technicians for research activities.

Figure 7.3.8 – New job creations by the innovation Union in EU-27, compared to the reference scenario and in thousands



Source: NEMESIS model

Impact on GDP and jobs in the EU-27 member states and in the UK Taking into account the impacts measured for the different countries, the large diversity of their innovation systems, and the distinct impacts that the individual commitments have in these systems, this should lead to very contrasted results, depending the category of system the country belongs to. We see from the country results for GDP in 2040, displayed in table 7.3.14, that this is confirmed by the figures in this table. For illustration, if we take the case of the second column, that corresponds to the medium case for the “Realistic” scenario, the nine countries that are characterized as “Strong innovators” by the Conceptual model of the European Union innovation systems, globally perform above the EU average in terms of progress provoked by the reinforcement of the Innovation Union in the scenario. There is only one exception, the Netherlands, that under-performs, with GDP gains well below the EU-27 average.

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Table 7.3.14 – GDP gains per country for 2040 , in percentages compared to the reference scenario

		'Realistic - Low'	'Realistic - Medium'	'Realistic - High'	'Optimistic - Low'	'Optimistic - Medium'	'Optimistic - High'
Strong innovators	Austria	2.50%	3.80%	5.20%	3.80%	6.00%	8.20%
	Belgium	1.40%	2.10%	2.80%	2.10%	3.30%	4.50%
	Germany	1.50%	2.50%	3.40%	2.40%	4.10%	5.80%
	Denmark	2.20%	3.30%	4.40%	3.30%	5.30%	7.20%
	Finland	2.00%	3.50%	5.10%	3.50%	6.10%	8.70%
	The Netherlands	0.80%	1.30%	1.70%	1.20%	2.10%	2.90%
	Sweden	1.90%	3.10%	4.30%	3.00%	5.00%	7.00%
	Slovenia	3.40%	5.10%	6.90%	5.20%	8.00%	10.80%
	UK	1.10%	1.90%	2.60%	1.70%	3.00%	4.30%
Publicly policy-led	France	0.90%	1.70%	2.40%	1.50%	2.80%	4.20%
	Ireland	1.90%	3.20%	4.40%	3.00%	5.10%	7.20%
	Italy	0.90%	1.30%	1.80%	1.30%	2.10%	2.90%
	Lithuania	0.90%	2.20%	3.50%	1.50%	2.80%	4.20%
	Luxembourg	1.40%	1.80%	2.10%	2.10%	2.70%	3.30%
	Latvia	0.80%	1.70%	2.80%	1.10%	2.20%	3.40%
	Poland	1.40%	2.40%	3.50%	2.20%	3.40%	4.70%
	Portugal	2.00%	3.00%	4.10%	3.00%	4.60%	6.30%
Developing	Cyprus	0.80%	1.40%	2.00%	1.10%	2.00%	2.90%
	Czech Republic	2.70%	3.60%	4.50%	3.80%	4.90%	6.10%
	Spain	1.60%	2.40%	3.30%	2.40%	3.80%	5.30%
	Hungary	0.10%	0.60%	1.20%	0.40%	1.00%	1.60%
	Romania	0.60%	1.10%	1.80%	0.90%	1.70%	2.60%
	Bulgaria	0.50%	1.80%	3.20%	0.90%	2.40%	4.00%
	Slovakia	0.40%	0.90%	1.50%	0.60%	1.10%	1.60%
Lagging-behind	Estonia	2.70%	5.50%	8.40%	4.80%	9.40%	14.10%
	Greece	1.40%	1.90%	2.60%	2.10%	3.00%	4.10%
	Malta	1.30%	2.10%	2.90%	2.10%	3.40%	4.60%
	EU-27	1.40%	2.20%	3.00%	2.10%	3.50%	4.90%

Source: NEMESIS model

*Reading: Highest figures in blue, medium in white, and lowest in red

For the second group of eight countries, the “Publicly policy-led”, the situation is more contrasted. In the Conceptual model of Innovation Union, what they have in common is that they are countries where innovation in the private sector is not particularly well-developed, contrary to public policy in the STI field that is developed and active. The situation in the different countries using the ranking of the European Innovation Survey are nevertheless very varied, with three countries classified as strong innovators: France, Luxembourg and Ireland, and five as moderate innovators: Latvia, Lithuania, Poland, Portugal, and Italy. On these eight countries, four over-perform compared to the EU average: Ireland, Lithuania, Poland and Portugal, and the four others under-perform.

In the third group, the seven countries with “Developing” innovation systems, five under-perform, one (Spain) performs just above the EU average, and one (Czech Republic) strongly over-performs. All the countries in this group are classified as Moderate or Modest innovators on the European Innovation Scoreboard. They form, like the “Strong innovators” group quite a homogeneous cluster of countries, with the difference that globally it under-performs compared to the average of the other EU countries.

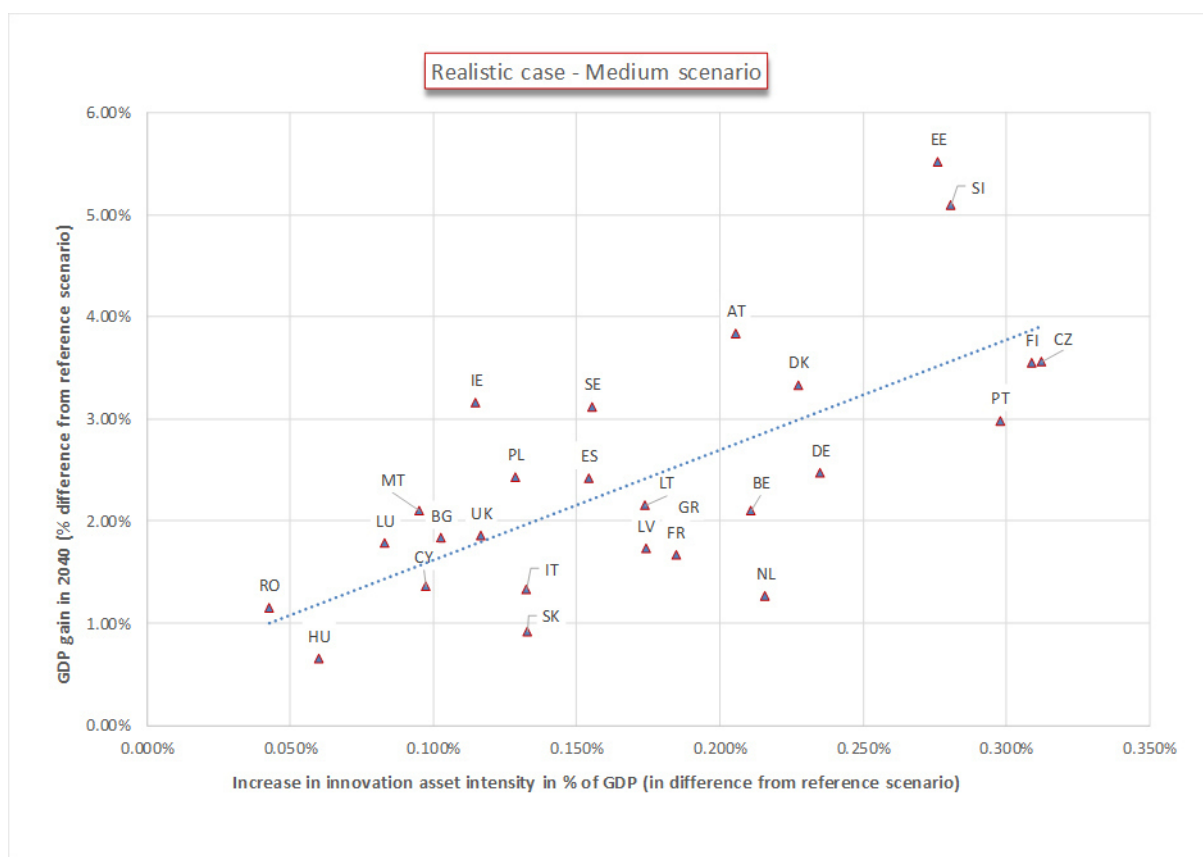
The three countries in the last group, the “Lagging-behind” countries, all are Moderate innovators in the European Innovation Survey. Two perform just below the EU average: Greece and Malta, and

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one well above: Estonia, and it is difficult to draw general conclusions for this group of countries at this stage of the analysis.

For GDP, figure 7.3.9 finally confirms for the “*Medium*” case in the “*Realistic*” scenario, the positive relationship we underlined above between the increase in innovation assets in % of GDP, and GDP gains. Nevertheless, this relationship is not one to one, and the overall result for GDP in the scenario is also strongly influenced by the increase in public research productivity and in knowledge spillovers in the different countries.

Figure 7.3.9 – The relation between GDP gains and the deviation of investment in innovation assets for the “*Medium*” case in the “*Realistic*” scenario



Source: NEMESIS model

Table 7.3.15 provides results for employment per country in 2040 in the six scenarios that were simulated using the model. As the results are in level, the colors in the table are not really relevant: the larger countries create the most employment in absolute terms. Therefore, for the medium case in the “*Realistic*” scenario, of the 784 thousand new jobs that progress in the Innovation Union would

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create, 153 would be in Germany, 72 in France, 69 in Italy, 77 in Poland, 98 in Spain, and the 315 thousand remaining in the other 22 other EU-27 countries.

Table 7.3.15 – Employment creation per country for 2040 in thousands compared to the reference scenario

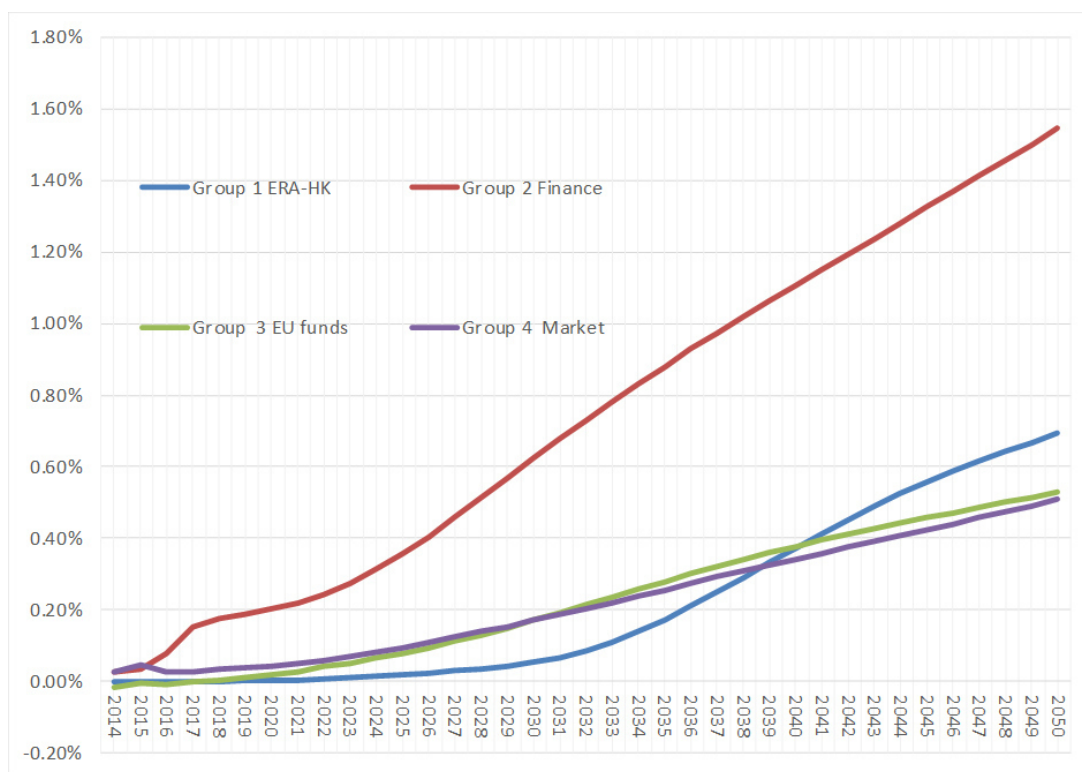
		'Realistic - Low'	'Realistic - Medium'	'Realistic - High'	'Optimistic - Low'	'Optimistic - Medium'	'Optimistic - High'
Strong innovators	Austria	25	38	49	37	56	72
	Belgium	10	15	19	15	22	30
	Germany	96	153	210	146	242	332
	Denmark	11	16	20	16	24	32
	Finland	7	12	18	12	21	30
	The Netherlands	10	14	19	14	23	32
	Sweden	19	30	41	29	47	64
	Slovenia	6	9	12	9	14	18
	UK	77	129	182	117	204	291
	Publicly policy-led	France	40	72	106	63	119
Ireland		9	15	21	14	24	33
Italy		45	69	96	65	106	149
Lithuania		1	3	5	2	5	7
Luxembourg		2	3	3	3	4	5
Latvia		2	4	6	2	5	7
Poland		41	77	116	65	108	153
Portugal		21	33	47	33	51	70
Cyprus		1	2	2	1	2	3
Developing		Czech Republic	22	31	41	31	42
	Spain	64	98	136	98	153	212
	Hungary	1	7	13	3	10	17
	Romania	12	24	38	18	36	54
	Bulgaria	8	29	49	13	37	62
	Slovakia	3	7	12	4	9	15
	Lagging-behind	Estonia	3	6	9	5	9
Greece		13	18	24	19	27	37
Malta		0	1	1	1	1	1
EU-27		471	784	1112	719	1196	1679

Source: NEMESIS model

*Reading: Highest figures in blue, medium in white, and lowest in red

The different impacts of the different categories of commitments over time Before continuing with the next sub-section on the individual impacts of the commitments and commitment groups, it is important to underline here, for the interpretation of the results we just presented, that the different categories of commitments have different impacts over time.

Figure 7.3.10 – The differentiated impacts on GDP of the different categories of commitments



Source: NEMESIS model

Figure 7.3.10 demonstrates that for GDP in the medium case in the “Realistic” scenario, that the impacts are stronger and faster in group 2- “Access to finance” than in the other groups. The impacts of the group 1 commitments- “Human-capital”, that act on the productivity of public research with a very indirect link to the market, are those for which the economic impacts take the longest time before they become significant: This begins after 2030. Then the impacts increase sharply and become superior to those of the two last groups of commitments after 2040. These two last groups, “EU funds” and “Access to market”, therefore remain in an intermediary position.

The consequence is that when analyzing the impact of the Innovation Union commitment as a whole using the model simulation, the conclusions that could be made on the relative impact in the different countries could be very different depending the time period studied, and the relative contribution of the different commitments to the results in each individual country. This now calls for an in-depth analysis on how individual commitments act in the different countries.

7.3.2.2 The individual impacts of the commitments at EU-27 level

Tables 7.3.16, 7.3.17, 7.3.18 and 7.3.19 summarize the individual impacts of the Innovation Union commitments and the commitment groups at the EU-27 level. We limit the presentation to the “Mean” case in the “*Realistic*” and “*Optimistic*” scenarios, as the detailed results for all the other cases are available in Excel format in Le Mouél (2019, [208]). For the “*Realistic*” scenario the results are displayed in table 7.3.16 for group 1 and group 2 commitments, and in table 7.3.17 for groups 3 and 4 commitments. The results for the “*Optimistic*” scenario and the four groups of commitments are displayed in tables 7.3.18 and 7.3.19.

In these tables, the two first columns display the direct impact of each commitment and group of commitments on public research productivity and R&D investment intensity (% of EU GDP). These impacts are provided from 2027 when they reach their maximum values that then stay (roughly) constant up to 2050. On one hand, public research productivity is supposed to be influenced only by Group 1 commitments- “*Human capital*”, that all aim at increasing public research productivity and therefore at reinforcing externalities from public research towards corporate research. On the other hand, R&D intensity (in % of GDP) mainly reflects the influence of the commitments in the three other groups, that following our implementation methodology in NEMESIS, are all supposed to increase private and/or public R&D investments.

The tables show the impacts of the commitments on the EU GDP in 2040 and 2050, in % deviation from the reference scenario. As we assumed in all the scenarios that the commitments implementation increases up to 2027, the commitment impacts reach their full potential from 2040, because of the time lags in the innovation mechanisms at play in NEMESIS. But, the impacts continue to develop after 2040 and up to 2050, when, most of the time, the deviation of the long term EU potential GDP growth rate has stabilized. The last column in the tables then indicates how the long term potential growth rate of EU GDP will be modified by the actions of the commitments. Furthermore, the tables also show the impacts on EU total employment in 2040 and 2050 (in thousands and in deviation from the reference scenario). While, like for EU GDP, these impacts on employment continue between 2040 and 2050, they will nevertheless stabilize thereafter, once the level of the structural unemployment rate has been reached.

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Table 7.3.16 – The individual impacts of commitments of groups 1 and 2 in the “Medium” case of the “Realistic” scenario

	IMPACT ON:							
	Public research productivity in %	R&D as % of EU GDP in diff. from reference scenario	EU27 GDP in % diff. From reference scenario		EU27 employment in thousand and in diff. from ref. scenario		EU27 potential GDP growth rate	
	from 2027	2027-2050	2040	2050	2040	2050		
Group 1 Commitments: "Human Capital"								
C2-2 "Knowledge alliances for skill gaps"	5.2%	0.003%	0.14%	0.26%	57	154	0.012%	
C3 "Propose an integrated framework for e-skill"	6%	0.003%	0.14%	0.27%	60	162	0.013%	
C4-2 "ERA - research mobility"	8.30%	0.004%	0.18%	0.34%	70	187	0.016%	
C30 "Foreign talents"	4%	0.002%	0.10%	0.18%	39	105	0.009%	
Joint implementation of Group 1 commitments (C2-2 + C3 + C30)	15.4%	0.0078%	0.37%	0.69%	157	405	0.032%	
Group 2 Commitments: "Finance"								
C10 "Put in place EU financial instruments to attract private finance"	-	0.010%	0.14%	0.18%	94	115	0.004%	
C11 "Access to finance- Venture capital"	-	0.042%	0.50%	0.72%	310	435	0.022%	
C12 "Access to finance - Matching"	-	0.027%	0.32%	0.45%	178	252	0.013%	
C13 "Review State aid framework for R&D and innovation"	-	0.048%	0.55%	0.77%	434	580	0.022%	
Joint implementation of Group 2 commitments (part of C10 + C11 + C13)	-	0.093%	1.11%	1.54%	775	1044	0.044%	

Source: NEMESIS model

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Table 7.3.17 – The individual impacts of commitments of groups 3 and 4 in the “Medium” case of the “Realistic” scenario

	IMPACT ON:							EU27 potential GDP growth rate
	Public research productivity in %	R&D as % of EU GDP in diff. from reference scenario	EU27 GDP in % diff. From reference scenario		EU27 employment in thousand and in diff. from ref. scenario			
			2040	2050	2040	2050		
	from 2027	2027-2050						
Group 3 Commitments: "EU funds"								
C6 "EU research and innovation programmes"	-	0.040%	0.34%	0.47%	242	322	0.013%	
C24/25 "ESI funds"	-	-0.001%	0.04%	0.06%	88	114	0.002%	
Joint implementation of Group 3 commitments (C6 + C24/25)		0.039%	0.38%	0.53%	332	437	0.015%	
Group 4 Commitments: "Action to market"								
C19-1 "Creative industries"	-	0.030%	0.34%	0.50%	217	318	0.016%	
C19-2 "EU design leadership board"	-	0%	-0.01%	0%	-7	-2	0%	
Joint implementation of Group 4 commitments (C19-1)	-	0.030%	0.34%	0.50%	217	318	0.016%	

Source: NEMESIS model

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Table 7.3.18 – The individual impacts of commitments of groups 1 and 2 in the “Medium” case of the “Optimistic” scenario

	IMPACT ON:							
	Public research productivity in %	R&D as % of EU GDP in diff. from reference scenario	EU27 GDP in % diff. From reference scenario		EU27 employment in thousand and in diff. from ref. scenario		EU27 potential GDP growth rate	
	2027-2050	2027-2050	2040	2050	2040	2050		
Group 1 Commitments: "Human Capital"								
C2-2 "Knowledge alliances for skill gaps"	11.3%	0.006%	0.30%	0.56%	124	329	0.027%	
C3 "Propose an integrated framework for e-skill"	13.4%	0.007%	0.32%	0.60%	134	356	0.028%	
C4-2 "ERA - research mobility"	18%	0.008%	0.38%	0.72%	149	399	0.034%	
C30 "Foreign talents"	8.7%	0.004%	0.21%	0.39%	86	227	0.019%	
Joint implementation of Group 1 commitments (C2-2 + C3 + C30)	33.4%	0.016%	0.79%	1.45%	331	838	0.066%	
Group 2 Commitments: "Finance"								
C10 "Put in place EU financial instruments to attract private finance"	-	0.025%	0.30%	0.42%	192	266	0.012%	
C11 "Access to finance- Venture capital"	-	0.057%	0.67%	0.96%	407	580	0.029%	
C12 "Access to finance - Matching"	-	0.053%	0.60%	0.87%	334	484	0.027%	
C13 "Review State aid framework for R&D and innovation"	-	0.064%	0.72%	1.02%	559	758	0.030%	
Joint implementation of Group 2 commitments (part of C10 + C11 + C13)	-	0.126%	1.49%	2.10%	1026	1405	0.061%	

Source: NEMESIS model

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Table 7.3.19 – The individual impacts of commitments of groups 3 and 4 in the “Medium” case of the “Optimistic” scenario

	IMPACT ON:							
	Public research productivity in %	R&D as % of EU GDP in diff. from reference scenario	EU27 GDP in % diff. From reference scenario		EU27 employment in thousand and in diff. from ref. scenario		EU27 potential GDP growth rate	
	2027-2050	2027-2050	2040	2050	2040	2050		
Group 3 Commitments: "EU funds"								
C6 "EU research and innovation programmes"	-	0.056%	0.49%	0.68%	345	465	0.019%	
C24/25 "ESI funds"	-	0.003%	0.08%	0.10%	145	163	0.002%	
Joint implementation of Group 3 commitments (C6 + C24/25)		0.062%	0.56%	0.78%	492	626	0.021%	
Group 4 Commitments: "action to market"								
C19-1 "Creative industries"	-	0.059%	0.66%	0.98%	407	621	0.033%	
C19-2 "EU design leadership board"	-	0.006%	0.06%	0.10%	7	39	0.004%	
Joint implementation of Group 4 commitments (C19-1)	-	0.059%	0.66%	0.98%	407	621	0.033%	

Source: NEMESIS model

The results for the “Realistic” scenario For the Group 1 commitments- “Human capital” in the “Realistic” scenario (see tables 7.3.16 and 7.3.17), their impact on public research productivity ranges from 4% (C30) to 8.3% (C4.2), and reaches about 15.4% when implemented jointly. The joint impact is inferior to the sum of the individual impacts insomuch as commitment 4.2 was omitted as it overlaps with the others. This 15.4% increase in public research productivity following the joint action of the Group 1 commitments, could increase the potential EU GDP annual growth rate by 0.032 point. The

gain in GDP would reach 0.37% in 2040 and 0.69% in 2050, and the gain in EU employment respectively 157,000 and 405,000.

For the Group 2 commitments- “*Finance*”, each of them could increase EU R&D intensity (% of GDP) between 0.01% (C10) to 0.048% (C13). These Group 2 commitments would jointly increase EU GDP R&D intensity by 0.093 point. And the joint action of these commitments could increase long term EU GDP annual growth rate by about 0.044 point, with +1.11% EU GDP in 2040 and +1.54% in 2050. They would also increase the level of the EU employment by 775,000 in 2040 and of 1,044,000 in 2050.

With the Group 3 commitments- “*EU funds*”, the main impacts come from the commitment 6 (EU R&I Programmes) while the impacts of commitments 24/25 (ESI funds) remain limited due to their weak implementation under the current multiannual financial framework (2014-2020). The joint impact of these commitments could increase EU GDP R&D intensity by 0.039 point with an impact on potential EU GDP annual growth rate of 0.015 point. For the EU GDP, the gains would amount to 0.38% in 2040 and to 0.53% in 2050. They would be respectively +332,000 and +437,000 for EU total employment.

For the two commitments in the last Group - “*Action to market*”, the only significant impacts are from commitment 19.1 (Creative industries), those of commitment 19.2 being very limited. Furthermore, commitment 19.2 overlaps with commitment 19.1 so it was removed from the joint assessment. With the commitment 19.1, the impact on EU GDP R&D intensity would be of about 0.030 point leading to an increase of potential EU GDP annual growth rate of 0.016 point. The gains in EU GDP would reach 0.34% in 2040 and 0.50% in 2050 and those in EU total employment respectively +217,000 and +318,000.

To summarize, the four groups of commitments would have very significant impacts on the EU innovation system and on the EU economy, if the commitments take place as defined in the “*Realistic*” scenario. They could:

1. Increase public research productivity by 15.4% (Group 1);
2. Increase EU GDP R&D intensity by 0.09 point (Group 2), 0.04 point (Group 3) and 0.03 point (Group 4);
3. Increase potential EU GDP annual growth rate by respectively 0.032 point (Group 1), 0.042 point (Group 2), 0.015 point (Group 3) and 0.016 point (Group 4);

4. Deliver EU GDP gains in 2040, ranging from +0.34% (Group 4) to +1.11% (Group 2) and in 2050 from +0.50% (Group 4) to +1.54% (Group 2);
5. Create employment in EU, from +157,000 units (Group 1) to +775,000 (Group 2) in 2040 and from +318,000 units (Group 4) to +1,044,000 (Group 2), in 2050.

Results for the “*Optimistic*” scenario In the case of the “*Optimistic*” scenario (see tables 7.3.18 and 7.3.19), the socioeconomic impacts are necessarily more significant at EU level than in the “*Realistic*” scenario. The different commitments and groups of commitments could:

1. Increase public research productivity by 33.4% (Group 1);
2. Increase the EU GDP R&D intensity by 0.13 point (Group 2), 0.06 point (Group 3) and 0.06 point (Group 4);
3. Increase potential EU GDP annual growth rate by 0.066 point (Group 1), 0.061 point (Group 2), 0.021 point (Group 3) and 0.033 point (Group 4);
4. Deliver EU GDP gains in 2040, ranging from +0.56% (Group 3) to +1.49% (Group 2) and in 2050 from +0.78% (Group 3) to +2.1% (Group 2);
5. Create employment in EU, from +331,000 units (Group 1) to +1,026,000 (Group 2) in 2040 and from +621,000 units (Group 4) to +1,405,000 (Group 2), in 2050.

7.3.2.3 The individual impacts of the commitments in the different EU countries and in UK

This last section prolongs the analysis of the action of the individual commitments with a focus on the situation in the different EU countries and in the UK. We will limit our comments here to the GDP figures for the “*Medium*” case in the “*Realistic*” scenario.

Figure 7.3.20 sums-up the GDP impact in 2040 of the four groups of commitments introduced in the model, on the four clusters of countries that the Conceptual model for the Innovation Union distinguishes. The reading is the same as previously, with in blue the higher figures, in white the medium and in the red the lowest.

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Table 7.3.20 – The individual impacts of commitments at country level

	Evolution of GDP in 2040	G1- "Human capital"				G2 - "Access to finance"				G3- "EU funds"		G4- "Market"	
		C2.2	C3	C4.2	C30	C10	C11	C12	C13	C6	C24/25	C19-1	C19-2
Strong innovators	Austria	0.39%	0.40%	0.56%	0.27%	0.32%	1.17%	1.50%	0.77%	0.69%	0.03%	0.35%	-0.01%
	Belgium	0.12%	0.12%	0.18%	0.08%	0.19%	0.62%	0.41%	0.31%	0.54%	0.03%	0.27%	-0.01%
	Germany	0.22%	0.20%	0.25%	0.15%	0.18%	0.68%	0.24%	0.61%	0.24%	0.02%	0.42%	-0.01%
	Denmark	0.29%	0.30%	0.53%	0.20%	0.21%	0.81%	0.42%	0.99%	0.49%	0.03%	0.36%	-0.01%
	Finland	0.28%	0.29%	0.41%	0.18%	0.25%	0.92%	1.05%	0.46%	0.85%	0.14%	0.69%	0.00%
	The Netherlands	0.08%	0.08%	0.19%	0.06%	0.08%	0.29%	0.26%	0.12%	0.39%	0.02%	0.19%	0.00%
	Sweden	0.34%	0.34%	0.56%	0.23%	0.31%	1.20%	0.83%	0.40%	0.54%	0.04%	0.22%	-0.01%
	Slovenia	0.19%	0.26%	0.19%	0.13%	0.25%	0.88%	0.39%	1.86%	0.98%	0.09%	0.76%	-0.01%
UK	0.11%	0.12%	0.18%	0.08%	0.06%	0.60%	0.75%	0.44%	0.07%	0.03%	0.45%	0.00%	
Publicly policy-led	France	0.11%	0.12%	0.14%	0.08%	0.11%	0.41%	0.23%	0.21%	0.19%	0.00%	0.49%	-0.01%
	Ireland	0.26%	0.27%	0.41%	0.19%	0.20%	0.79%	1.19%	0.34%	0.67%	0.01%	0.78%	-0.01%
	Italy	0.05%	0.06%	0.03%	0.03%	0.09%	0.29%	0.22%	0.43%	0.22%	0.01%	0.17%	-0.01%
	Lithuania	0.03%	0.10%	0.04%	0.03%	0.02%	0.08%	0.03%	1.00%	0.15%	0.77%	0.09%	0.00%
	Luxembourg	0.14%	0.18%	0.49%	0.10%	0.00%	0.02%	0.11%	1.18%	0.20%	0.03%	0.08%	0.00%
	Latvia	0.01%	0.02%	0.01%	0.01%	0.03%	0.10%	0.13%	0.61%	0.20%	0.66%	0.14%	0.00%
	Poland	0.02%	0.00%	0.04%	0.01%	0.05%	0.17%	0.06%	1.58%	0.04%	0.51%	0.13%	0.00%
	Portugal	0.04%	0.03%	0.02%	0.03%	0.06%	0.19%	0.03%	1.37%	0.50%	0.20%	0.45%	-0.01%
Developing	Cyprus	0.02%	0.02%	0.03%	0.45%	0.04%	0.17%	0.15%	0.11%	0.71%	0.10%	0.12%	0.00%
	Czech Republic	0.03%	0.06%	0.01%	0.03%	0.08%	0.28%	0.53%	2.77%	0.07%	0.28%	0.05%	0.00%
	Spain	0.08%	0.10%	0.06%	0.05%	0.11%	0.36%	0.15%	0.69%	0.64%	0.04%	0.36%	-0.01%
	Hungary	0.04%	0.05%	0.02%	0.03%	0.06%	0.21%	0.33%	-0.03%	0.09%	0.27%	0.04%	0.00%
	Romania	0.04%	0.04%	0.05%	0.03%	0.07%	0.24%	0.19%	0.23%	0.19%	0.21%	0.17%	0.00%
	Bulgaria	0.02%	0.03%	0.03%	0.02%	0.06%	0.22%	0.82%	0.21%	0.29%	0.99%	0.09%	0.00%
Lagging-behind	Slovakia	0.04%	0.04%	0.06%	0.03%	0.02%	0.00%	0.01%	0.49%	0.04%	0.41%	0.05%	0.00%
	Estonia	0.20%	0.25%	0.26%	0.12%	0.14%	0.58%	0.42%	1.12%	0.72%	0.43%	2.05%	0.00%
	Greece	0.05%	0.06%	0.05%	0.04%	0.06%	0.22%	0.08%	0.42%	0.81%	0.04%	0.20%	0.00%
	Malta	0.02%	0.04%	0.02%	0.01%	0.12%	0.31%	0.50%	0.43%	0.44%	0.04%	0.74%	0.02%
	EU-27	0.14%	0.14%	0.18%	0.10%	0.14%	0.50%	0.32%	0.55%	0.34%	0.04%	0.34%	-0.01%

Source: NEMESIS model

For the first group of commitments, “*Human capital*”, the results of the model confirm the analysis of the “*Conceptual model*” that these commitments, that aim globally at reinforcing the quality of research in universities and research institutes, as well as the collaboration between public and private research, and the attraction of foreign talents, should benefit more from the strongest innovation systems, with the strongest actors, in that way widening the gap with the countries with “*Developing*”, or “*Lagging-behind*” systems. The only noticeable exception is Estonia in the “*Lagging-behind*” group. For the last group of countries, “*Publicly policy-led*”, the situations are more contrasted, as this group is more heterogeneous, regrouping countries that are classified in the EIS as “*Strong*” and “*Modest*” innovators.

For the second group of commitments, “*Access to finance*”, the three first (10, 11 and 12) aim at mobilizing private funds to finance private firms’ innovation and are also classified by the Conceptual

model as commitments that may increase the divergence between the strongest and the weakest innovation systems in Europe. This analysis is again confirmed by the simulation results of the NEMESIS model, with similar contrasts as previously described, for the impacts on GDP between these two broad categories of countries. For the last commitment (13) of the Group “*Finance*”, the revision of the General Block Exemption Regulation (GBER) that aims at making national grants of RDI aids more efficient, the results for GDP at national level for innovation systems are more contrasted within each category. The Conceptual model of the union classifies this commitment among those that may help convergence, and concerning the results the NEMESIS model shows a more homogeneous result for this commitment than for the three other commitments for “*Finance*”, and the four commitments in the “*Human capital*” group. The strongest impacts are, for example, for the Czech Republic (+2.77%) that is classified as “*Developing*”, Slovenia (1.86%) that is a “*Strong innovator*” and for Poland (+1.37%) and Portugal (+1.37%) that are in the “*Publicly policy-led*” category and are only moderate innovators in the EIS country ranking. On the other hand the weakest impacts are found for three countries in the “*Developing*” group that are classified among the weakest countries by the EIS: Bulgaria (+0.21%), Romania (+0.23%) and Hungary (-0.03%). As for the others, Cyprus is classified as “*Developing*”; France (0.21%) and Ireland (+0.34%) are classified as “*Publicly policy-led*”; and The Netherlands (+0.12%) and Belgium (+0.31%) that are considered “*Strong*” innovators.

For the third group of commitments, “*EU funds*”, the spectrum of results also indicates strong impacts in countries with weak innovation systems, but also for the countries that belong to the “*Strong innovators*” group. The Conceptual model of innovation classifies these commitments in the group that may increase the divergence between the national innovation systems in Europe, mostly because of the argument that no major progress for the inclusiveness of the countries in the east and the south of Europe, with generally weak innovation systems, could be observed in the FP7 programme. The geographical distribution of these EU R&I funds has not evolved much under the H2020 programme, but some of these “*Lagging-being*” countries, such as Estonia and Greece, or countries that are only “*Moderate innovators*” in the EIS, anyway succeed and benefit from these funds well above the EU average, when measured by the amount of subsidies they receive from the EU as a percentage of their GDP (see figure 5.4.3). Therefore, though the results of the NEMESIS model broadly confirm that the R&I framework programmes, where the allocation of funds is based on “*excellence*”, favors countries with the strongest innovation systems, nevertheless, there are notable exceptions. For the two other commitments in this group, for the share of ESI funds for R&I, the geographical allocation this time

follows a principle of inclusion of the weaker countries. The results of the NEMESIS model clearly confirm this classification of these two commitments by the Conceptual model of the Innovation Union, as being among those that favor convergence between the innovation systems in Europe.

For the fourth group of commitments, “*Action to market*”, that are considered as commitments that should increase convergence in the conceptual model, the findings of the NEMESIS model are more mitigated. For commitment 19-2, “*EU design leadership board*”, the GDP impact is nearly null because little progress is expected from the analysis of recent trends in the implementation of this commitment over the next years. Figure 7.3.20 nevertheless suggests that a widest implementation of this commitment in Europe would benefit the countries with the weakest systems more, but no conclusion can really be drawn for this commitment from the NEMESIS model results. For commitment 19-1, “*Creative industries*”, the higher GDP impacts are for the “*Strong innovators*”, as well as for two countries in the “*Publicly policy-led*” group that are strong innovators in the EIS: France and Ireland. But for the weakest countries, like Portugal, Spain, Malta and Estonia, that are all “*Moderate innovators*” in the EIS, the strongest impact for this commitment is found in Estonia (+2.05%), followed by Ireland (+0.78%), Slovenia (+0.76%), Malta (+0.74%) and Finland (+0.69%).

Table 7.3.21 summarizes the results of table 7.3.20 by this time providing the GDP impacts of each individual commitment in each innovation group, by indicating, for each group and each commitment, the mean GDP impact calculated as a direct average of the GDP percentage increase in the different countries for each category of innovator. This table confirms, that for the seven first commitments, that the Conceptual model classifies as “*having a potential for increasing divergence*” under current trends. The “*Strong innovators*” and “*Publicly policy-led*” groups are generally blue to indicate the GDP impact of the commitments, while the other two groups of countries are generally red or only “*pink*”. Once again, blue is for highest figures, red the lowest, white medium. The picture is globally the reverse of that of the other commitments, that the conceptual model considers as promoting convergence between the various innovation systems.

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Table 7.3.21 – The individual impacts of commitments in the different categories of national systems of innovation

		Strong innovators	Publicly policy-led	Developping	Lagging-behind	EU-28
Group 1- "Human capital"	C2.2	0.22%	0.18%	0.03%	0.09%	0.14%
	C3	0.24%	0.22%	0.04%	0.12%	0.14%
	C4.2	0.34%	0.18%	0.02%	0.11%	0.18%
	C30	0.15%	0.13%	0.08%	0.06%	0.10%
Group 2 - "Access to finance"	C10	0.21%	0.33%	0.06%	0.10%	0.14%
	C11	0.80%	0.46%	0.21%	0.37%	0.50%
	C12	0.65%	1.04%	0.31%	0.33%	0.32%
	C13	0.66%	1.11%	0.64%	0.65%	0.55%
Group 3- "EU funds"	C6	0.53%	0.53%	0.29%	0.66%	0.34%
	C24/25	-0.03%	0.56%	0.33%	0.17%	0.04%
Group 4- "Ac. to market"	C19-1	0.41%	0.29%	0.10%	0.99%	0.34%
	C19-2	-0.01%	0.00%	0.00%	0.00%	-0.01%

Source: NEMESIS model

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Table 7.3.22 – The individual impacts of commitments for the innovators groups of the EIS

	Innovation leaders	Strong innovators	Moderate innovators	Modest innovators	EU-28
C2.2	0.24%	0.19%	0.04%	0.04%	0.14%
C3	0.24%	0.21%	0.05%	0.04%	0.14%
C4.2	0.38%	0.31%	0.03%	0.05%	0.18%
C30	0.17%	0.13%	0.06%	0.03%	0.10%
C10	0.21%	0.16%	0.07%	0.07%	0.14%
C11	0.78%	0.64%	0.23%	0.24%	0.50%
C12	0.56%	0.62%	0.20%	0.19%	0.32%
C13	0.52%	0.73%	0.82%	0.23%	0.55%
C6	0.50%	0.48%	0.36%	0.19%	0.34%
C24/25	-0.05%	-0.01%	0.28%	0.21%	0.04%
C19-1	0.38%	0.45%	0.34%	0.17%	0.34%
C19-2	-0.01%	-0.01%	0.00%	0.00%	-0.01%

Source: NEMESIS model

Finally, table 7.3.22 also summarizes the results of table 7.3.20, but for the innovator groups on the European Innovation Scoreboard. It provides a similar picture, confirming the overall consistency of the evaluation that the I3U project provided for the Innovation Union commitments, either commitment by commitment, or by commitment groups, or as a whole.

7.3.3 Summarizing the conclusions on the perspectives of the Innovation Union under current trends

The second question the I3U investigated is what socioeconomic impacts could be expected following the progress of the Innovation Union in future years? This quantification was achieved with the NEMESIS model, based on the inputs provided by the other partners of the project, using the results of the direct impact assessment of the individual commitments that the commitments' expert teams performed.

The methodology of the assessment The individual analysis of the commitments by the different partners involved in the the I3U project revealed that only 24 quantitative targets were followed, and that of these 24, there are only 13 for which there exists sufficiently robust data to show their impact on the innovation mechanisms represented in the NEMESIS model. Four groups of commitments were finally considered, because of the type of action they have on the European innovation system:

1. Group 1 - "*Human capital*" includes four commitments that all promote the development of human capital and skills that could for example impact on the productivity of research or increase knowledge spillovers. These commitments are:
 - 2.2 - "*Knowledge alliances for skill-gaps*";
 - 3 - "*Propose an integrated framework for e-skills*";
 - 4.2 - "*ERA research mobility*";
 - 30 - "*Foreign talents*".
2. Group 2 - "*Finance*", regroups commitments aiming to facilitate the financing of firms' innovation, and notably the access to finance for SMEs. Its four commitments are:
 - 10 - "*Put in place EU financial instruments to attract private financing*";
 - 11 - "*Access to finance - Venture capital*";

- 12 - “Access to finance – Matching”;
 - 13 - “Review State aid framework for R&D and innovation”.
3. Group 3 - “European funds”, includes three commitments focusing on the impact of EC funds:
- 6 - “EU research and innovation programmes”;
 - 24/25 - “Improve/Increase the use of ESI funds for R&I”.
4. Group 4 - “Action to market”, finally regroups commitments aiming at fostering market conditions for innovation. There are two commitments:
- 19.1 - “Creative industries”;
 - 19.2 - “EU design leadership board”.

Then, two scenarios were simulated for each commitment:

1. A *scenario based on “current trends”* in the implementation of the commitment in the different countries and/or, depending on the case, at EU level. We call this the “*Realistic*” scenario.
2. A *scenario based on more ambitious targets* for commitment implementation. This was designed to stay attainable by implementing additional policies, and by amplifying policies already in place. We call this the “*Optimistic*” scenario.

Whatever the scenario considered, the simulations quantified the impacts that will result from the progress achieved in the commitments implementation between 2013 and 2027. After 2027, the commitments implementation was supposed not increase any further. To evaluate the long term impacts of the commitments, the NEMESIS model was simulated from 2014 up to 2050.

By adapting this methodology for the specificities of the individual commitments, we could finally evaluate their socioeconomic impacts on different time horizons, commitment by commitment, by group of commitments, and as a whole.

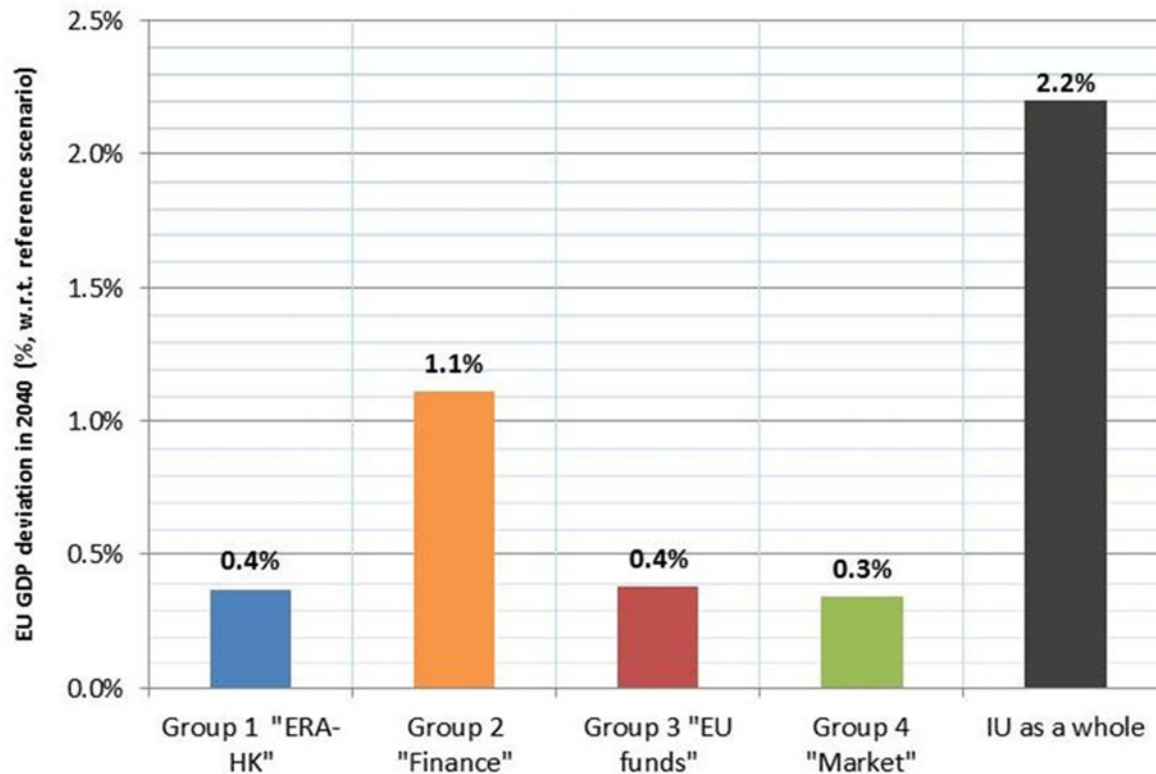
As there is a lot of overlapping between the actions supported by the different commitments, when assessing them by groups or as a whole, we were obliged, to avoid double-counting in the global impact, to leave some aside. There are four of these:

- 4.2 - “ERA/Research mobility”;
- part of 10 - “RSFF/InnovFin”;

- 12 - “Access to finance – Matching”;
- and 19.2 - “EU design leadership board”.

What can we expect if the Innovation Union continues under current trends? Taking year 2040 to summarize the main results, so that R&I policies have enough time to reach their full potential, using the NEMESIS model we evaluated that “as a whole”, the progress observed in the Innovation Union under current trends could increase the level of EU-27 GDP by 2.2%, compared to a situation where no progress would occur in the implementation of the Innovation Union after 2013.

Figure 7.3.11 – Impacts on EU-27 GDP in 2040 for the “Medium” case of the “Realistic” scenario

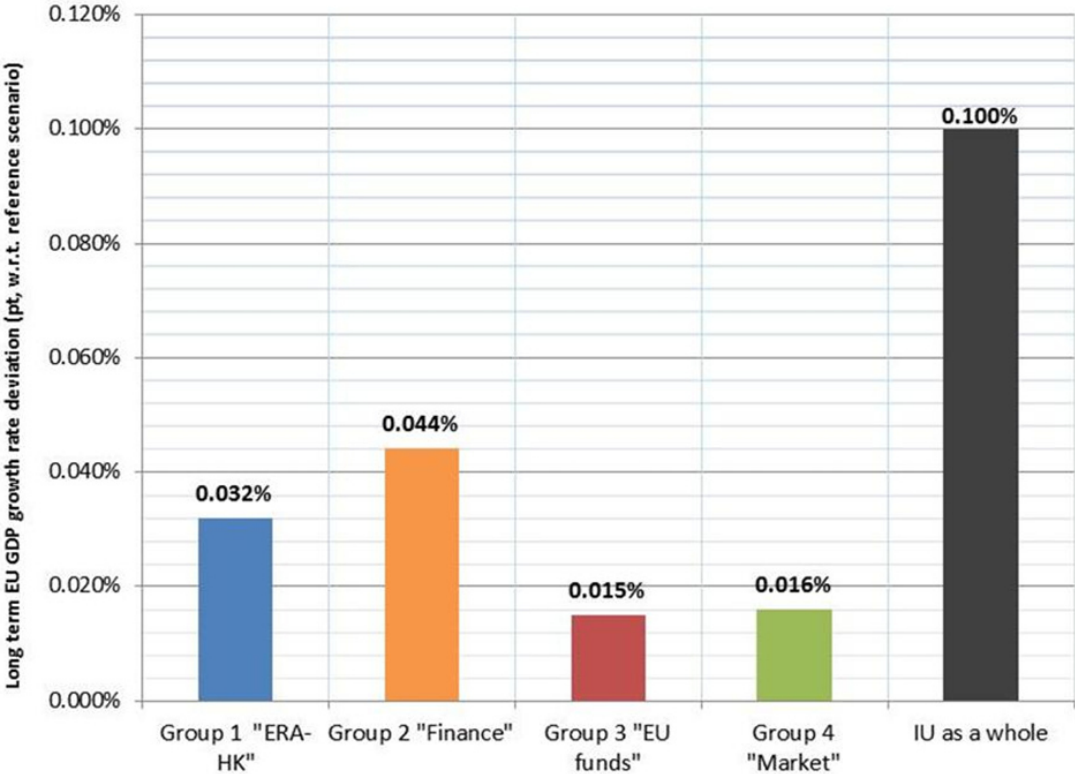


Source: NEMESIS model

Of the 2.2% additional GDP (see figure 7.3.11), 0.4% comes from the impact of the EU funds. As ESI funds for R&I do not show much evolution for the whole 2013-2027 period, these 0.4% mainly reflect the influence of the H2020 and Horizon Europe framework programmes. A comparable impact on GDP is expected from ERA and human capital related policies (Group 1 commitments - “Human

capital”), for which, to our knowledge, no similar calculation of impacts at macro level was available before the I3U project. Group 2 commitments, that all leverage funds for the financing of private R&I investment, are not surprisingly those with the highest impact: they contribute to nearly 50% of the final result. The RSFF and InnovFin financial tools have certainly contributed significantly to the strong increase in VC investment in recent years. This should continue to be an important trend in the near future. For the Group 4 commitments, all the impacts come from the huge development of creative industries, that are an important enabler for innovation in a wide range of sectors. Much is to expected from the commitments aiming at increasing standardization (16) or at developing innovative public procurements (17), but it was not possible at this stage to provide any quantification for their potential impacts.

Figure 7.3.12 – Impacts on EU-27 GDP long-term annual growth rate for the “Medium” case in the “Realistic” scenario



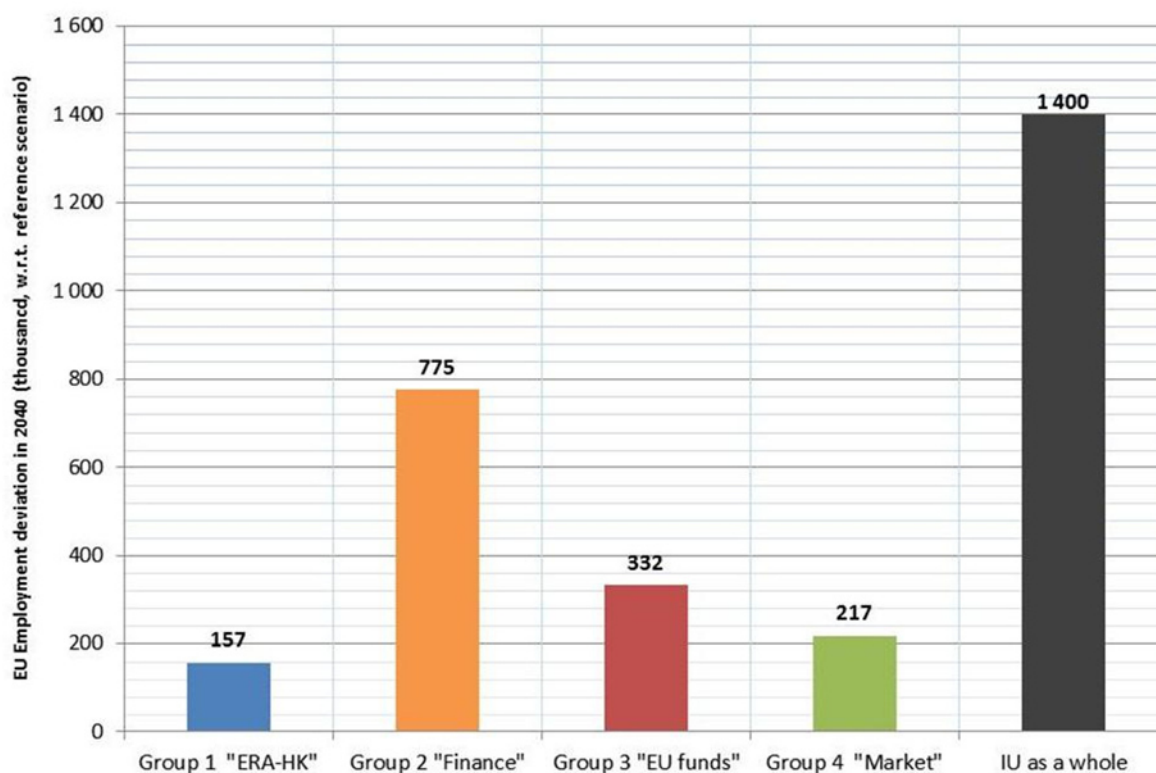
Source: NEMESIS model

Figure 7.3.12 displays the impacts of the EU-27 GDP annual growth rate in the long term (calculated for 2040-2050). We see that the progress of the Innovation Union could increase the EU-27 potential

Chapter 7. Investigating the Impacts of the Innovation Union (I3U)

GDP growth rate by 0.1% under current trends, which is an important increase as this is currently estimated at about 1.3% in the 2018 European Ageing report. The contribution to these 0.1% by the Group 1 commitments - “*ERA-HK*”, with 0.032%, is particularly important, as it is twice the contribution estimated for the groups “*Access to market*” and “*EU funds*” (about 0.015%), and close to the one estimated for the “*Finance*” group (0.044%). This reflects the strong, long-term impact of policies aimed at increasing and diffusing general knowledge, as compared to policies that focus more closely on the market.

Figure 7.3.13 – Results for employment in 2040 for the “*Medium*” case in the “*Realistic*” scenario



Source: NEMESIS model

Figure 7.3.13 displays the results for employment, showing that, under current trends, up to 1.4 million new jobs could be created in 2040, thanks to the progress of the Innovation Union. Of these 1.4 million, about 332 thousand would come from the impact of EU funds contributed mainly by the EU R&I programmes. The other contributions are 775 thousand for “*Finance*”, 217 thousand for “*Action to market*” and 157 thousand for “*ERA-HK*”.

Finally, when considering the impacts of the individual commitments in the different countries, the

results of the NEMESIS model globally confirm the main conclusions of the Conceptual model of the Innovation Union that was developed in the context of the project: under their current implementation, there are commitments that profit the countries with the strongest innovation systems, with the risk of increasing the divergence between the strongest and the weakest innovation systems in Europe. Of the thirteen commitments that were implemented in the NEMESIS model, there are all the Group 1 commitments - “*Human capital*”, and three of the four Group 3 commitments - “*Access to finance*”. All the other commitments are, on the contrary, more likely to increase the convergence between the different EU countries, like the commitments 24/25 for ESI funds, or to impact the different categories of countries and of national innovation systems more homogeneously. This current tendency for certain commitments to increase the divergence between national innovation systems could certainly be reversed, by re-focusing their action more explicitly on developing actors in the countries with “*Developing*” or “*Lagging-behind*” innovation systems.

The impacts of a more ambitious scenario The progress of the Innovation Union under current trend is slow and its socioeconomic impacts, while substantial, remain rather limited, and more important impacts could be obtained by reinforcing current policies. For that, we have simulated using the NEMESIS model, a more ambitious scenario that notably:

- Sets the budget of Horizon Europe to 90 billion in constant terms (+20%);
- Reinforces the share of ESI funds for R&I for 2021-2027 by +12 billion Euros (raising the share of ERDF funds to R&I to 25%, as compared to 20% under current trends);
- Assumes an additional increase of 33% in the development of investments financed by the Eu-VECA financial instrument;
- Increases the implementation of commitment 2.2 fostering private/public knowledge transfers to 2.4% per year, as compared to 1.2% per year in the current trends scenario.

By reinforcing current policies and current trends in this way, the rise of the EU GDP intensity in 2027 could reach 0.24 point (against 0.16 point under current trends), leading to +3.5% in EU GDP (against +2.2%), to an increase of 0.16 point (against 0.1 point) in the potential EU GDP growth rate and 2.2 million (against 1.4 million) additional jobs in the EU in 2040.

If we also take into account the contribution of the increase in EU GDP R&D intensity of 0.26 point between 2007 and 2013 (from 1.75 to 2.01), using the NEMESIS model, in the first part of this chapter

we have evaluated that it could bring up to 2.8% additional GDP in the EU by 2040, increasing the potential EU GDP growth rate by about 0.07 point, with the creation of 3.2 million additional jobs in 2040.

To sum up, with the progress in the EU's innovation potential from 2007 to 2013, added to that expected for the period 2014 to 2027, we obtain a rise in EU GDP of between 4.9% and 6.2% for 2040, an increase in the potential EU GDP growth rate of between 0.17 point and 0.23 point, and between 4.6 and 5.4 million new jobs. Finally, EU R&D intensity would reach 2.25% in 2027, +0.5 point compared to the its pre-crisis level. Therefore, after the financial crisis, the progress of the Innovation Union undoubtedly already had important positive effects on EU R&D intensity, growth, employment and competitiveness. Nevertheless, under the current trends, and whatever the scenario simulated with the NEMESIS model, the progress will be insufficient to reach the objective of closing the gap in R&D intensity with that of the world leaders in innovation (like US, Japan and Korea), and to reach the Europe 2020 objective of 3% of EU GDP invested in R&D.

7.4 Summary of the main findings of I3U project from its final report

This last section ends the presentation of the I3U project with a summary of its main conclusions, **as they were drawn by the project partners in the I3U final report**²⁷ that will be available soon on the I3U project web-site.

The aim of the project was to perform an in-depth evaluation of the Innovation Union flagship initiative, that is one of the seven flagship initiatives of the Europe 2020 strategy, and that consists of 34 commitments intended to improve innovation performance in the EU.

“The I3U project has [therefore] assessed the progress in the implementation of the Innovation Union, the strength and the weakness of each commitment, the coherence, completeness and effectiveness of the 34 commitments within the holistic framework of an innovation system, deriving recommendations on the implementation of the Innovation Union initiative. Finally, the I3U project has provided the quantitative evaluation, individually and as a whole, of those commitments for which reli-

²⁷Consequently this concluding section is not an original contribution but is here in order to provide to the reader with a complete vision of the project results and conclusions, that have not already been published at the time we write these lines. The paragraphs directly taken from the I3U final report are in italics.

able data and robust estimated marginal effects exist within the framework of a macroeconomic model (NEMESIS)”.

7.4.1 The state of the Innovation Union and recommendations for future improvements

The Innovation Union commitments current impacts have to a large extent been evaluated by the project partners, and have proven to have globally yielded their desired effects. Notwithstanding, about a third of the commitments have not yet or have only partially been implemented. Individual analysis of the 34 commitments reached four main conclusions:

- *“Firstly, that there is a high fragmentation of research along country boundaries, accompanied by a lack of transparency and a duplication of research efforts”;*
- *“Secondly, there is a lack of micro data needed to enable an accurate evaluation of some of the commitments”;*
- *“Thirdly, a majority of the commitments tend to increase the innovation divide between countries in the EU”;*
- *“Fourthly, there are sometimes conflicts in interest between the EU and some local or sectorial interests”.*

Following these conclusions, three key recommendations for improving the Innovation Union in the future were finally formulated. We cite them as they are in the I3U final report:

Recommendation 1 – Convergence and divergence of European innovation systems *“Some of the Innovation Commitments are likely to lead to divergence in terms of innovation capabilities, either because of the very nature of the commitment (e.g., because the implied policy is targeted at innovation leaders), or because the commitment is implemented in various degrees in the different member states of the EU”.*

“This leads to the following recommendations at the commitment level (C1/ C3/ C4/ C5/ C6/ C10/ C11/ C13/ C14/ C18/ C30)”:

“There are a number of commitments that are especially important in the parts of the EU that are lagging behind in terms of innovation (e.g., the developing and lagging-behind innovation systems

identified in the project). Strong implementation of these commitments in these weaker parts of the EU will lead to stronger convergence and cohesion. However, there are no specific policy measures aimed at strengthening the implementation of these commitments in the weaker parts of the EU. Such a strengthening could be achieved by explicitly linking these commitments to Commitments 24 and 25, which are concerned with the use of the Structural Funds for innovation purposes. This holds specifically for Commitment 1 (training of researchers and improving employment conditions of researchers), Commitment 3 (e-skills), Commitment 4 (European Research Area, ERA), Commitment 5 (research infrastructures), Commitment 6 (research and innovation programmes), Commitment 10 (financial instruments to attract private finance), Commitment 11 (attract venture capital), Commitment 13 (review state aid frameworks), Commitment 14 (unitary patent), Commitment 18 (eco-innovation), Commitment 30 (attracting foreign talent). For some of the commitments (1, 3, 4, 5, 6, 10, 11, 18) in this list that require significant investment of resources, we recommend that their implementation is specifically linked to the Structural Funds, with financial resources from the Structural Funds made available for such implementation. For the commitments in the list that do not depend crucially on investment of resources (13, 14, 30), we recommend a specific revision of the policy aimed at making it more effective in countries with weaker innovation systems”.

Recommendation 2 – Better monitoring commitment implementation and outcomes “The analysis for some of the commitments has been severely hampered because of serious limitations in available data. Sometimes, this is due to the nature of the commitment, e.g., because it does not provide clear aims and goals so that measurement is difficult, and sometimes this is due to absence of (publicly available) data sources”.

“More attention should be given to making available relevant data, leading to the following recommendation for specific commitments (C7/ C12/ C16/ C17/ C19/ C22/ C23/ C31)”:

“New key indicators need to be developed to measure important dimensions of the policy commitments. Existing data sources are often aimed at measuring “how much” rather than at “how well”. This holds for Commitment 7 (SMEs in research programmes – we can measure the quantity of such participation, but not the quality of it), Commitment 12 (access to finance – the commitment asks for better matching but this is not sufficiently quantified), Commitment 17 (public procurement – hardly any data exist), Commitment 19 (creative industries and design), Commitment 22 (European market for IPR – there is a specific need for databases stemming from other sources than the patent offices),

and Commitment 31 (cooperation with third countries – we can measure the quantity of such cooperation, but not the quality of it). Also, the availability of micro data on firms or other agents is often crucial for proper monitoring of policy. Without sufficiently rich (number and type of variables) and longitudinal micro data, causality (i.e., whether the policy really makes a difference) is often impossible to establish. This holds for Commitment 7 (SMEs in research programmes), Commitment 16 (standardization – which needs in particular data combining information on standards, innovation and performance), Commitment 19 (creative industries and design), and Commitment 23 (safeguard rules for IPR)”.

Recommendation 3 – Adjustment and intensification of policy measures “The analysis in the project yielded specific conclusions about potential adjustment of the policies implied by the Innovation Union commitments, or about their intensification”.

“At the commitment level, this leads to the following recommendations (C7/ C8/ C11/ C15/ C17/ C18/ C20/ C21/ C26/ C27/ C28/ C29)”:

“In Commitment 7 (SME participation in research and innovation programmes), the new FP9 can build on the successful implementation of this commitment in previous Framework Programmes, by continuing the specific attention to SME participation, and by devoting a larger amount of resources to this end. Also, better coordination of EU-level and national policies in the topic of this commitment is called for. In Commitment 8 (forward looking activities), wider dissemination of policy and foresight papers, especially from the JRCs would make the policy more efficient. In Commitment 11 (access to finance – venture capital), a stronger emphasis on diffusion and implementation across the EU of the InnovFin instrument is called for. For Commitment 15 (screening of regulatory frameworks), a continued effort at more implementation vigor is recommended from the analysis, since implementation has not been complete in any member state. For Commitment 17 (public procurement), an effort to spread awareness and use of the public procurement tool is necessary. In Commitment 18 (eco-innovation), more attention to the demand side, e.g., by measures aimed at changing the consumer’s mindset are called for. In Commitment 20 (open access publishing), more attention is needed to the receivers’ side, e.g., measures aimed at absorptive capacity in SMEs. For Commitment 21 (collaborative research and knowledge transfer), a number of policy reforms have already been suggested by previous literature, e.g., aimed at increasing the resources available for Technology Transfer Offices (TTOs) and strengthening their role in general. For Commitment 26 (social innovation), the analysis showed a

general lack of coordination of policies and even a common working definition. Social innovation may have a potential for positive change, but it needs to be targeted in a more comprehensive and coordinated way. In Commitment 27 (public innovation), the decision to not implement a public sector innovation scoreboard should be followed up by new and systematic initiatives to monitor and foster innovation in the public sector. For Commitment 28 (social partners), a general lack of implementation was observed, and a recommendation for clarifying the goals and aims of this commitment can be given. For Commitment 29, a refocusing towards activities targeting genuine frontier innovation would increase the effectiveness of the policy. For Commitment 32 (global research infrastructures), the MERIL database could be developed into a comprehensive and up to date source of information”.

7.4.2 The evaluation of the Innovation Union socioeconomic impacts

“The Innovation Union constitutes indeed a systemic approach to stimulating innovation in Europe. It addresses a wide range of capabilities, mostly in the area of research and innovation and mostly involving the actors of higher education, research institutions, private firms, and government, and less so the financial intermediaries and the consumers. Almost 50% of the commitments of the Innovation Union concern interactions between agents. About 25% of them concern the relief of obstacles to innovation and 25% the implementation of conditions necessary to its achievement. However, the analysis has shown that there is not one innovation system in Europe but four groups of systems, the most strongly developed in all dimensions, the publicly-policy-led, where the private sector is not as developed but public policy is very active, the developing one, which is strongly dependent on external knowledge and competencies, and the lagging behind where public policy is relatively weak”.

“An important result of the project was the adaptation of the macro model NEMESIS for the evaluation of the different commitments that constitute the Innovation Union”.

“Thirteen of these commitments, that pursue quantitative objectives and for which there exists data for measuring them, have finally been ‘implemented’ in the model, and their socioeconomic impacts have been evaluated. It is the first time that a global assessment of the IU has been provided with the help of a macro simulation model”.

“The simulation results have showed the importance of the Innovation Union if the commitments implementation continues at the same trend as in the past. Then the Innovation Union will allow to create more than 1.4 million jobs in 2040, improve, in relative value, the potential rate of growth of Europe by 7%, and the EU R&D intensity by 0.16%. If the commitments implementation would

accelerate up to a always feasible rate, then the job creations would reach 2.2 million, the relative rate of growth of the EU 10%, and the R&D intensity 0.25%. We must add that in the two scenarios, “Finance” group has the most important impact, and the “Market” group the most immediate results. By contrast, the “Human capital” group takes time to produce economic impacts, but reveal to deeply improve the growth rate of the EU in the long term. However, the progresses are slow - the economic impacts would take additional time to develop - and won’t permit to close the gap in R&D intensity between Europe and the world leaders in research and innovation”.

“Finally, the I3U assessment of the IU did not consider all the progress achieved after the 2007-2008 economic crisis, but only from 2013 onward. If we add the progress measured by the European Innovation Scoreboard since the crisis, we obtain, already in 2018, an increase of 1.1 million jobs and 1.3% rise of EU GDP. We can expect for 2040, up to a 6.2% increase in GDP (+0.23 point for EU GDP long -term growth rate) and 5.4 million new jobs. The EU R&D intensity would therefore reach 2.25% from 2027, +0.5 point compared to the pre-crisis level”.

Chapter 8

Conclusion

Now at the end of this thesis, we will simply add a few concluding remarks on the progress already made in the macroeconomic evaluation of EU innovation policies, and on any possible future improvements and evolutions.

The first remark, it was apparent from the survey of the econometric literature on R&I in chapter 2, and the presentation of the growth theories in chapter 3, that the development of these is what constitutes the ingredients out of which the macro simulation models used for evaluation of EU R&I policies are built. This development has been very gradual and it continues slowly.

On the empiric side, it took decades following statements by Solow (1957, [301]), that about 87.5 % of growth of output per man and the productivity increase in the United States for the period 1909-49, was caused by exogenous forces “(...) attributable to technical change and the remaining 12.5 per cent increase to increased use of capital” (Solow, *ibid*, p. 320), to provide a satisfactory representation of the forces that were at the origin of this 87.5% of “*unexplained*” growth. Abramovitz’s invitation (1956, [1]) to economists, to concentrate their attention on the “*cause of economic growth*” proved to be a success, and by the end of the 1990s, with the development of growth accounting techniques and the distinction between different categories of labor and capital inputs to better measure the Solow residual, the measured contribution of the residual to output growth per capita in the US was considerably reduced: from 87.5% in 1957 to 17% only.

Besides this progress in describing growth, the econometric literature on R&D and productivity brought a very important empirical contribution to explain the role played by R&D investments and knowledge externalities in the process of growth. According to this literature, a large part, if not all of the Solow residual; the “*unexplained*” growth in the growth accounting approach; is attributable to R&D investment by private firms and to the knowledge externalities provoked by investments in research by corporate and public sectors. This literature has notably shown that output elasticities to private R&D are high, exceeding two to four times their factor share, and may contribute to productivity growth for at least 0.1 to 0.2 point per year and even more if we also take into account the contribution of public R&D. A key finding was certainly the predominant contribution of knowledge spillovers, that are at the source of these “*excess returns*”, and explain that the estimated social returns to R&D, are found, to be on average, 50% to 100% superior to private ones, with “(...) mean social rates of returns (*i.e. private plus spillovers*) to R&D to the order 90-100%” (Wieser, 2005, page 614, [280]). All these results were made possible by the progressive development of the methodologies developed for measuring R&D externalities, from the seminal works by Telecky (1974, [308]) using input-output matrices, to the more

recent and sophisticated approaches based on patent citation techniques, developed from the 1980s, that were increasingly used from the mid-1990s, thanks to the digitization of patent data and the development of computational power.

On the theoretical side, it also took a long time to reshape the RCK neoclassical model of economic growth, and endogenize technical change in it.

For that, the indispensable ingredient was the introduction of imperfect competition in the initial model proposed by Solow (1956, [300]) and Swan (1956, [306]), so as to propose a model adapted to the “*knowledge-based economy*” where technical change results from investments in R&I by profit-seeking firms motivated by the creation and the exploitation of monopoly rents. The new model, like Shell (1973, [296]) first proposed in 1973, should presumably include, with possible variants, (1) a research sector with free entry, where the discovery of new ideas results from investments in research, whose productivity is pushed-up by the accumulation of past knowledge resulting from past innovations by all innovators, (2) an intermediate sector, buying new ideas from the research sector that intermediate firms transform into innovations, thus providing them with monopoly rents protected by patents, and (3) a final goods sector, with pure and perfect competition, where the productivity increase results from the improvement of the set of intermediates (from horizontal or vertical innovations) used for producing the final output, similarly to the role played by the exogenous technical change in the Solow model.

Shell did not have the necessary analytical tools at the time he wrote his article to represent the imperfect competition that is implied by the increasing returns provoked by the knowledge spillovers in the model. It was therefore necessary to wait and build on the progress made elsewhere in the economic literature, until the first generation of NGT models were introduced. The first was the model of horizontal differentiation proposed by Romer (1990, [284]) in 1990, where the introduction of imperfect competition was based on the original model of imperfect competition proposed by Ethier (1982, [114]) in the context of international trade theory. Then there was the model of vertical differentiation proposed by Grossman and Helpman (1991, [152]) and Aghion and Howitt (1992, [4]), where imperfect competition was alternatively inspired by the modern theories of industrial organization and the patent race models developed by Tirole (1988, chapter 10, [238]) and Reinganum (1989, [279]).

We saw all the progress accomplished since these initial models, in the second generation of models, and the most recent developments in the literature, with the introduction of firms’ heterogeneity.

The second remark is that the “*compromise*” between the facts and the theories, that form the

different macro models used for the evaluation of EU R&I policies (chapter 4), is conditioned to a certain extent, by various delays that influence the development of the models, and, to another extent, by the modeling choices.

As illustrated above, there are delays between the appearance of a new phenomenon, and the time the necessary data, empirical and theoretical studies, are developed and robust enough, to introduce them in the models. For example, in the case of NEMESIS, the extension of the innovation mechanisms of the model to the specific role played by investment in ICT and in intangible assets other than R&D, presented in chapter 5, was only very recently made possible. The first version of the EU-KLEMS database, on ICT investments, only became available in 2007, and the first version of the INTAN-INVEST database, for intangible investments, in 2014. These data are neither complete, nor do they cover all the countries (for EU-KLEMS), or all the sectors (for INTAN-INVEST). What is more, applied and theoretical literature on the role that the ICT and the different categories of intangibles play for innovation in the different sectors, also remains very scarce. The means used to introduce these latter in the NEMESIS model are therefore still very tentative. Therefore there is the hope that this modeling could be improved in the future, with the development of the data, like the new SPINTAN (Smart Public Intangible) database offering, from 2017, data measuring intangible capital in the public sector, like the INTAN-INVEST database does for private firms. This will allow, for example, a better representation of innovation in the health, or public education sectors, that are central elements in regards to the challenges posed by the ageing European population, and the need for a well-educated population to accompany the fast structural change in modern knowledge-based economies.

Concerning the specific modeling choices retained in the different models, we saw in chapter 4 that they are to a large extent conditioned by the general aim pursued by the different models.

QUEST, conceived mainly for analyzing EU competition, fiscal and budgetary policies, is the most in line with modern macroeconomic growth theories. But this is at the cost of the richness of the innovation mechanisms in the model, that are restricted by the forward-looking expectations, and the high theoretical constraints, imposed by the DSGE modeling. For RHOMOLO, built for the analysis of regional policies and the evaluation of the impacts of ESI funds, the limitation, for the representation of innovation, comes from the high level of “granularity” of the model, that prevents the description of certain phenomena at such a detailed geographical level, like for knowledge spillovers. NEMESIS, specifically designed for the evaluation of R&I policies, and the analysis of other structural policies, such as those related to energy and environment, is therefore the model that includes the richest

innovation mechanisms when comparing the main findings in the literature. It notably includes a crucial distinction, between the effects of process and of product innovation. The recent extension of its innovation mechanisms to the role played by investments in ICT, software and professional training, is particularly important when representing innovation in the service sectors.

No model is perfect and no model can answer all questions; but as we saw in the case of NEMESIS, in chapters 6 and 7, when carefully used, by gathering information from past assessments, and by re-calibrating the key model parameters using the most recent data and econometric estimates, models can nevertheless bring very useful, and very in-depth macroeconomic evaluations of EU R&I policies.

So, what will the future of the macroeconomic evaluation of EU R&I policies be? It is difficult to answer that question precisely. The only thing that is sure, is that the three models we have presented in this thesis will continue to improve, and modify their “*compromise*”, with the advances made in data, in empirics, and in theories; that is to say with the advances made in science. An example of this is the integration of firms’ heterogeneity in the theoretical models of economic growth, that could lead to important future improvements in the macro models, if the data are made available.

Finally, new models will almost certainly appear in the landscape, which should *per se* represent a huge improvement, in the coming years, for the macroeconomic evaluation of EU R&I policies.

BIBLIOGRAPHY

- [1] Moses Abramovitz. Resource and Output Trends in the United States since 1870. *The American Economic Review*, 46(2):5–23, 1956.
- [2] Ram Acharya and Susanto Basu. *ICT and Total Factor Productivity Growth: Intangible Capital or Productive External Ties?* Industry Canada, 2011.
- [3] P. Aghion, A. Bergeaud, T. Boppart, P.J. Klenow, and H. Li. Missing Growth from Creative Destruction. 2017.
- [4] P. Aghion and P. Howitt. A model of growth through creative destruction. *Econometrica*, 60(2):323–351, 1992.
- [5] P. Aghion and P. Howitt. Joseph Schumpeter lecture appropriate growth policy: A unifying framework. *Journal of the European Economic Association*, 4(2-3):269–314, 2006.
- [6] Philippe Aghion, Nicholas Bloom, Richard Blundell, Rachel Griffith, and Peter Howitt. Competition and Innovation: An Inverted U Relationship. *The Quarterly Journal of Economics*, 120:701–728, 2005.
- [7] Philippe Aghion, Christopher Harris, Peter Howitt, and John Vickers. Competition, Imitation and Growth with Step-by-Step Innovation. *Review of Economic Studies*, 68:467–492, 2001.
- [8] Philippe Aghion and Peter Howitt. *Endogenous Growth Theory*. MIT Press, Cambridge, 1998.
- [9] Philippe Aghion and Peter Howitt. *The Economics of Growth*. The MIT Press, Cambridge Massachusetts, London, England, 2009.
- [10] U. Akcigit, C. Benedetti-Fasil, G. Impullitti, O. Licandro, and M. Sanchez-Martinez. *Macroeconomic Modelling of Innovation Policy*. Palgrave Macmillan, 2019 - Forthcoming.
- [11] U. Akcigit and W.R. Kerr. Growth Through Heterogeneous Innovations. *Journal of Political Economy*, forthcoming, 2017.
- [12] Ufuk Akcigit. Economic Growth: the Past, the Present and the Future. *Journal of Political Economy*, 125(6), 2017.
- [13] Mario Amendola and Jean-Luc Gaffard. Time to Build and Out-of-Equilibrium Growth Process. *Structural Change and Economic Dynamics*, 29:19–27.

BIBLIOGRAPHY

- [14] I.D. Anic, M. Cincera, M. Jokic, A. Mervar, Pellens M., B. Peters, E. Rajh, A. Santos, and B. Skrinjaric. Promoting openness and capitalizing on Europe's creative potential - State of implementation and direct impact assessment. *I3U project deliverable D5.2*, 2018.
- [15] K.J. Arrow. The economic implications of learning by doing. *The Review of Economic Studies*, pages 155–173, 1962.
- [16] W.B. Arthur. Competing Technologies, Increasing Returns and Lock-In by Historical Events. *Economic Journal*, 99:116–31, 1989.
- [17] Hall B. Measuring the Returns to R&D: The Depreciation Problem. *Annales d'Economie et de Statistique*, 79/80.
- [18] E. Bacchiocchi and F. Montobbio. International knowledge diffusion and home-bias effect: Do USPTO and EPO patent citations tell the same story? *Scandinavian Journal of Economics*, 112:441–470, 2010.
- [19] Sara Barcenilla-Visús, Carmen López-Pueyo, and Jaime Sanaú. Semi-Endogenous Growth Theory Versus Fully-Endogenous Growth Theory: a Sectoral Approach. Technical report, Mimeo. University of Zaragoza, 2010.
- [20] R. Barro and X. Sala-i Martin. Convergence. *Journal of Political Economy*, 100:223–51, 1992.
- [21] W. Baumol. Productivity Growth, Convergence and Welfare: What the Long-Run Data Show. *The American Economic Review*, 76(5):1072–85.
- [22] W.J. Baumol. Macroeconomics of unbalanced growth: the anatomy of urban crisis. *The American Economic Review*, 57(3):415–426, 1967.
- [23] W.J. Baumol and W.G. Bowen. On the Performing Arts: the Anatomy of their Economic Problems. *The American Economic Review*, 55(1/2):495–502, 1965.
- [24] M. Beck, M. Junge, and U. Kaiser. On the effects of Research and development- A literature review. *DEA report for the Danish Agency for Science Technology and Innovation*, 2017.
- [25] G.S. Becker. *Human Capital, A Theoretical and Empirical Analysis*. Columbia University Press for the NBER, New York, 1964.

BIBLIOGRAPHY

- [26] R. Belderbos and P. Mohnen. SIMPATIC Project, Deliverable D7: Intersectoral and international R&D spillovers. Technical report, MERIT, 2013.
- [27] M.L. Bemelmans-Videc, R.C. Rist, and E. Vedung. *Carrots, sticks and Sermons: Policy Instruments and their Evaluation*. Tranaction Publishers, London, 2003.
- [28] J.I. Bernstein and P. Mohnen. International R&D Spillovers between U.S. and Japanese R&D Intensive Sectors. *NBER Working Paper No. 4682*, 1994.
- [29] J.I. Berstein and I.M. Nadiri. Product demand, cost of production, spillovers and the social rate of return to R&D. *NBER Working Paper No 3625*, 1991.
- [30] Federico Biagi. *ICT and Productivity: A Review of the Literature*, volume 9. Publications Office, 2013.
- [31] Olivier Blanchard. On the Future of Macroeconomic Models. *Oxford Review of Economic Policy*, 34(1-2):43–54.
- [32] N. Bloom, M. Schankerman, and J. van Reenen. *Identifying Technology Spillovers and Product Market Rivalry*, 81:1347–1393, 2013.
- [33] F. Bogliacino and M. Pianta. Innovation and employment: a reinvestigation using revised pavitt classes. *Research Policy* 39 (6), 623, 2010.
- [34] B. Boitier, P. Le Mouel, P. Zagame, H. Brozaitis, J. Espasa, V. Stanciauskas, R. Wintjes, and P. Mohnen. Support for Assessment of Socio-Economic and Environmental Impacts (SEEI) of the European R&I Programme; the Case of Horizon Europe. *European Commission KI-02-18-999-EN-N*, 2018.
- [35] S. Borrás and C. Edquist. The choice of innovation policy instruments. *Technological Forecasting & Social Change*, 80:1513–1522, 2013.
- [36] M.J. Boskin. *Toward a more accurate measure of the cost of living: final report*. United States Senate, Committee on Finance, 1996.
- [37] B.P. Bosworth and J.E. Triplett. The early 21st century US productivity expansion is still in service. *International Productivity Monitor*, 14:3, 2007.

BIBLIOGRAPHY

- [38] D. Bosworth. The rate of obsolescence of technical knowledge spillovers - a note. *Journal of Industrial Economics*, 26:273–79, 1978.
- [39] Laura Bottazzi and Giovanni Peri. The International Dynamics of R&D and Innovation in the Long-Run and in the Short-Run. *The Economic Journal*, 117:486–511, 2007.
- [40] D. Brecard, A. Fougeyrollas, P. Le Mouel, L. Lemiale, and P. Zagame. Macro-economic consequences of European research policy: Prospects of the Nemesis model in the year 2030. *Research Policy*, 35(7):910–924, 2006.
- [41] Dorothee Brecard, Carole Chevallier, Arnaud Fougeyrollas, Pierre Le Mouel, Lionel Lemiale, and Paul Zagame. A 3% r&d effort in europe in 2010: an analysis of the consequences using the nemesis model. Technical report, DG RTD, 2004.
- [42] T. Bresnahan. Measuring the spillovers from technical advance: mainframe computers in financial services. *American Economic Review*, 76:742–755, 1986.
- [43] T. F. Bresnahan and M. Trajtenberg. «General Purpose Technologies: Engines of Growth». *Journal of Econometrics*, 65(1):83–108, 1995.
- [44] T.F. Bresnahan. The mechanisms of information technology’s contribution to economic growth. *Institutions, innovation and growth: selected economic papers*, page 116, 2003.
- [45] T.F. Bresnahan, E. Brynjolfsson, and L.M. Hitt. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence. *Quarterly Journal of Economics*, 117(1):339–376, 2002.
- [46] E. Brynjolfsson and S. Yang. Information Technology and Productivity: A Review of the Literature. *Academic Press*, 1996.
- [47] Erik Brynjolfsson. Technology’s True Payoff. *Information Week*, 10:34–36, 1994.
- [48] Erik Brynjolfsson and Lorin M. Hitt. Computing Productivity: Firm-Level Evidence. *Review of economics and statistics*, 85(4):793–808, 2003.
- [49] J.I. Bulow, J.D. Geanakoplos, and P.D. Klemperer. Multimarket Oligopoly: Strategic Substitutes and Complements. *The Journal of Political Economy*, 93(3):488–511, 1985.

BIBLIOGRAPHY

- [50] J. Caballero and A.B. Jaffe. *How High Are the Giants' Shoulders: An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth*, volume 8. 1993.
- [51] G. Cameron. Innovation and growth: A survey of the empirical evidence. *Nuffield College, Oxford, July*, <http://hicks.nuff.ox.ac.uk/users/cameron/research/gpapers.html>, 3, 1998.
- [52] Kenneth I Carlaw and Richard G Lipsey. Externalities, Technological Complementarities and Sustained Economic Growth. *Research Policy*, 31(8):1305–1315, 2002.
- [53] D. Cass. Optimum Growth in an Aggregative Model of Capital Accumulation. *Review of Economic Studies*, 32:233–40.
- [54] B. Cassiman, R. Veugelers, and P. Zuniga. In search of performance effects of (in) direct industry science links. *Industrial and Corporate Change*, 17:611–646, 2008.
- [55] F. Catellacci, M. Gulbrandsen, C. Mee Lie, and T. Thune. State of Implementation and Direct Impact Assessment. *I3U project deliverable D1.2*, 2017.
- [56] G. Cerulli and B. Poti. Heterogeneity of innovation strategies and firms' performance. *CERIS Working Paper 200706*, 2007.
- [57] Carole Chevallier, Arnaud Fougeyrollas, and Pierre Le Mouël. A Time to Sow, a Time to Reap for the European Countries: a Macro-Econometric Glance at the RTD National Action Plans. *Revue de l'OFCE*, (5):235–257, 2006.
- [58] M. Cincera. Firms' Productivity Growth and R&D Spillovers: An Analysis of Alternative Technological Proximity Measures. *Economics of Innovation and New Technology*, 2005.
- [59] Michele Cincera and Anabela Santos. Innovation and Access to Finance - State of Implementation and Direct Impact Assessment. *I3U project deliverable D3.2*, 2018.
- [60] K.B. Clark and Z. Griliches. *Productivity Growth and R&D at the Business Level: Results from the PIMS data base*. Chicago, IL: University of Chicago Press, 1984.
- [61] I.M. Cockburn and R.M. Henderson. Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery. *Journal of Industrial Economics*, 46:157–182, 1998.
- [62] D. Coe, E. Helpman, and A. Hoffmaister. North-South R&D Spillovers. *Economic Journal*, 107:134–149, 1997.

BIBLIOGRAPHY

- [63] David T Coe and Elhanan Helpman. International R&D Spillovers. *European Economic Review*, 39(5):859–887, 1995.
- [64] Wesley M. Cohen and Daniel A. Levinthal. Innovation and Learning: the Two Faces of R&D. *The Economic Journal*, 99:569–596, Septembre 1989.
- [65] W.M. Cohen and D.A. Levinthal. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35:128–152, 1990.
- [66] W.M. Cohen, R.R. Nelson, and J.P. Walsh. Links and impacts: The influence of public research on industrial R&D. *Management Science*, 48:1–23, 2002.
- [67] A. Colecchia and P. Schreyer. ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case? A Comparative Study of Nine OECD Countries. *OECD Science, Technology and Industry Working Papers*, 2001.
- [68] A. Colecchia and P. Schreyer. La contribution des technologies de l’information et des communications a la croissance économique dans neuf pays de l’OCDE. *Revue économique de l’OCDE*, (1):165–186, 2002.
- [69] European Commission. Annex to Proposal to the Council and European Parliament Decisions on the 7th Framework Programme (EC and Euratom) - Impact Assessment and Ex-Ante Evaluation. *Commission Staff Working Paper, SEC(2005) 430*, 2005.
- [70] European Commission. Europe 2020 Flagship Initiative Innovation Union. *SEC(2010) 1161*, 2011.
- [71] European Commission. In-Depth Interim Evaluation of Horizon 2020, commission staff working document, swd(2017) 221 final - 222 final. Technical report, European Commission, 2017.
- [72] European Commission. A New Horizon for Europe - Impact Assessment of the 9th EU Framework Programme for Research and Innovation. *European Commission - KI-02-18-513-EN-N*, 2018.
- [73] C. Corrado, J. Haskel, C. Jona-Lasinio, and M. Iommi. Intangible investment by industry - update 2014. Database, August 2014.
- [74] Carol Corrado, Jonathan Haskel, Cecilia Jona-Lasinio, and Massimiliano Iommi. *Intangible Capital and Growth in Advanced Economies: Measurement Methods and Comparative Results*. IZA, 2012.

BIBLIOGRAPHY

- [75] Carol Corrado, Jonathan Haskel, Cecilia Jona-Lasinio, and Massimiliano Iommi. Intangibles and Industry Productivity Growth: Evidence from the EU. In *IARIW 33rd General Conference*, 2014.
- [76] Carol Corrado, Charles Hulten, and Daniel Sichel. Measuring capital and technology: an expanded framework, 2005.
- [77] Carol Corrado, Paul Lengermann, Eric J Bartelsman, and J Joseph Beaulieu. Sectoral Productivity in the United States: Recent Developments and the Role of IT. *German Economic Review*, 8(2):188–210, 2007.
- [78] Carol A Corrado, Jonathan Haskel, and Cecilia Jona Lasinio. Knowledge Spillovers, ICT and Productivity Growth. Technical report, CEPR Discussion Paper No. DP10057, 2014.
- [79] Guido Cozzi. Exploring Growth Trajectories. *Journal of Economic Growth*, 2:385–398, 1997.
- [80] Dirk Crass and Bettina Peters. Intangible Assets and Firm-Level Productivity. 2014.
- [81] Bruno Crépon, Emmanuel Duguet, and Jacques Mairesse. Research, Innovation and Productivity: An Econometric Analysis at The Firm Level. *Economics of Innovation and New Technology*, 7(2):115–158, 1998.
- [82] Gustavo Crespi, Chiara Criscuolo, and Jonathan Haskel. Information Technology, Organisational Change and Productivity. 2007.
- [83] P. Cuneo and J. Mairesse. L’impact de la recherche-developpement sur la productivite industrielle . *Economie et Statistique*, 164:3–15, 1993.
- [84] D. Czartnitzki and K. Kraft. Spillovers of innovations activities and their profitability. *Oxford Economic Papers*, 64:302–22, 2012.
- [85] Jorgenson D. Technology in Growth Theory. In Jeffrey G. Fuhrer and Jane Sneddon Little, editors, *Technology and Growth*, pages 45–77. Jeffrey G. Fuhrer and Jane Sneddon Little, Federal Reserve Bank of Boston, Conference series Nb 40, 1996.
- [86] P. Dagupsa and J. Stiglitz. Industrial Structure and the Nature of Innovative Activity. *Economic Journal*, 90:266–293, 1980.

BIBLIOGRAPHY

- [87] J. P. Damijan, C. Kostevc, and M. Stare. Impact of innovation on employment and skill upgrading. The Warwick Economics Research Paper Series (TWERPS 339, SIMPATIC 7th EU Project, Working paper nÂ°7, March, 2014.
- [88] F.P.A.-R. D’Auria and J. Varga. A Comparison of Structural Reform Scenarios across the EU Member States: Simulation-based Analysis using QUEST Model with Endogenous Growth. *DG ECFIN, European Economy. Economic Papers 392.*, 2009.
- [89] A. d’Authume and P. Michel. Endogenous Growth in Arrow’s Learning by Doing Model. *European Economic Review*, 37:1175–1184, 1993.
- [90] Francesco Daveri. Information Technology and Productivity Growth Across Countries and Sectors. 2003.
- [91] P. David. Clio and the Economics of QWERTY. *American Economic Review*, 75:332–337, 1985.
- [92] P.A. David. The dynamo and the computer: an historical perspective on the modern productivity paradox. *The American Economic Review*, pages 355–361, 1990.
- [93] Hall B. David A. and Toole A. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy*, 29:497–529, 2000.
- [94] J. Davidson, D. Hendry, F. Srba, and S. Yeo. Econometric Modelling of the Aggregate Time-series Relationship Between Consumers’ Expenditure and Income in the United-Kingdom. *The Economic Journal*, (88):661–692, 1978.
- [95] Dealroom. Dealroom.com 2016 Venture Capital Report. 2017.
- [96] Angus Deaton and John Muellbauer. An Almost Ideal Demand System. *The American economic review*, pages 312–326, 1980.
- [97] H. Delanghe, Sloan B., and Muldur U. European research policy and bibliometrics indicators, 1990-2005. *Scientometrics*, 87:389–398, 2011.
- [98] Henri Delanghe and Ugur Muldur. Ex-ante impact assessment of research programmes: The experience of the european union’s 7th framework programme. *Science and Public Policy*, 34(3):169–183, 2007.

BIBLIOGRAPHY

- [99] Francesco Di Comite and d'Artis Kancs. Macroeconomic Models for R&D and Innovation Policies. *IPTS Working Papers on Corporate R&D and Innovation - No. 02/2015*, 2015.
- [100] C. Dimos and G. Pugh. The effectiveness of R&D subsidies: A meta-regression analysis of the evaluation literature. *Research Policy*, 45:797–815, 2016.
- [101] Elias Dinopoulos and Peter Thompson. Schumpeterian Growth Without Scale Effects. *Journal of Economic Growth*, 3(4):313–335, 1998.
- [102] Avinash K. Dixit and Joseph E. Stiglitz. Competition and Product Diversity. *The American Economic Review*, 67(3):297–308, 1977.
- [103] E. Domar. Capital Expansion, Rate of Growth and Employment. *Econometrica*, 14(2):137–47.
- [104] P. Donselaar and C.C. Koopmans. The fruits of R&D: Meta-analyses of the effects of Research and Development on productivity. *Research Memorandum 2016-1, Vrije university*, 45:797–815, 2016.
- [105] Kurt Dopfer. Mesoeconomics: Bridging Micro and Macro in a Schumpeterian Key. In *Sectors Matter!*, pages 103–114. Springer, 2011.
- [106] Kurt Dopfer. The Origins of Meso Economics. *Journal of Evolutionary Economics*, 22(1):133–160, 2012.
- [107] Giovanni Dosi. Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Direction of Technical Change. *Research Policy*, 11:147–62, 1982.
- [108] Giovanni Dosi. *Technical Change and Industrial Transformation*. London: MacMillan, 1984.
- [109] L.M. Ducharme and Mohnen P. Externalities et taux de rendement sociaux de la R&D. *Economies et Societes*, 8:189–213.
- [110] E3MLab. GEM-E3 Reference Manuel. 2017.
- [111] M. Eberhardt, C. Helmers, and H. Strauss. Do Spillovers Matter When Estimating Private Returns to R&D? *Revue of Economics and Statistics*, 95(2):436–448., 2013.
- [112] ECDG and Elsevier. Overall Output of Select Geographical Group Comparators and Related FP7 and H2020-Funded Publication Output. *Final report*, 2017.

BIBLIOGRAPHY

- [113] S. Englander, R. Evenson, and M. Hanazaki. Recherche-Developpement, Innovation et Flechissement de la Productivite Totale des Facteurs. *Revue Economique de l'OCDE*, 11:7–47, 1988.
- [114] Wilfred J. Ethier. National and International Returns to Scale in the Modern Theory of International Trade. *American Economic Review*, 72:389–405, 1982.
- [115] European Commission. The grand challenge - the design and societal impact of horizon 2020. Technical report, Directorate-General for Research and Innovation, 2012.
- [116] Eurostat. Annual sector accounts. Database, June 2014.
- [117] M. Falk. What drives business research and development intensity across OECD countries. *Applied Economics*, 38:533–547, 2006.
- [118] John G Fernald and Charles I Jones. The Future of US Economic Growth. Technical report, National Bureau of Economic Research, 2014.
- [119] Dominique Foray and Christopher Freeman. *Technology and the Wealth of Nations*. London: Pinter, 1993.
- [120] A. Fougeyrollas, B. Le Hir, P. Le Mouel, and P. Zagame. Macro-Economic Evaluation of Innovation Policies: A New Frame by NEMESIS. 2015.
- [121] A. Fougeyrollas, P. Le Mouel, and Zagame P. Les nouvelles theories de la croissance en application: l'evaluation des politiques structurelles, le cas du protocole de Kyoto. *Revue Economique*, 56(5), 2005.
- [122] Arnaud Fougeyrollas, Boris Le Hir, Pierre Le Mouël, and Paul Zagamé. Working Paper on References Scenarios with a New Model Developments of NEMESIS. Technical Report Deliverable D10.3, SEURECO, SIMPATIC Project D10.3, 2014.
- [123] Arnaud Fougeyrollas, Pierre Le Mouel, and Paul Zagame. Consequences of the 2010 fp7 budget on european economy. Technical report, SEURECO - Demeter Working Paper, 2010.
- [124] Arnaud Fougeyrollas, Pierre Le Mouël, and Paul Zagamé. Consequences of the FP7 2012 call on European economy and employment. Technical report, DEMETER Project; Report for the European Commission, 2011.

BIBLIOGRAPHY

- [125] Marvin Frankel. The Production Function in Allocation and Growth: A Synthesis. *The American Economic Review*, 52(5):996–1022, 1962.
- [126] C. Freeman, C. Perez, and GB). Science Policy Research Unit University of Sussex (Brighton. *The diffusion of technical innovations and changes of techno-economic paradigm*. Science Policy Research Unit University of Sussex, 1986.
- [127] C. Freeman and L. Soete. Technical change and full employment. 1987.
- [128] Milton Friedman. The Role of Monetary Policy. *American Economic Review*, 58(1):1–17, 1968.
- [129] J.C. Fuhrer and J.S. Little, editors. Federal Bank of Boston, Conference Proceedings, June, 1996.
- [130] F.A. Gabardo, J.B. Pereira, and Einloft P. The incorporation of structural change into growth theory: A historical appraisal. *Economia*, 2017.
- [131] D. Garcia-Maria, C.-Tai Hsieh, and P.J. Klenow. How Destructive is Innovation? *Econometrica (forthcoming)*, 2019.
- [132] M. Gittelman and B. Kogut. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. *Management Science*, 49:366–382, 2003.
- [133] R.J. Gordon. Monetary policy in the age of information technology: computers and the solow paradox. In *conference Monetary Policy in a World of Knowledge-Based Growth, Quality Change, and Uncertain Measurement, Bank of Japan, Corrected version*, 1998.
- [134] RJ Gordon. Does the 'New Economy' Measure Up to the Great Inventions of the Past? *Journal of Economic Perspectives*, 14(4):49–74, 2000.
- [135] Akira Goto and Kazuyuki Suzuki. R & D Capital, Rate of Return on R & D Investment and Spillover of R & D in Japanese Manufacturing Industries. *The Review of Economics and Statistics*, pages 555–564, 1989.
- [136] R. Griffith, Redding S., and van Reenen J. Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. 2001.
- [137] Rachel Griffith, Stephen Redding, and John Van Reenen. R&D and Absorptive Capacity: Theory and Empirical Evidence. *Scandinavian Journal of Economics*, 105(1):99–118, 2003.

BIBLIOGRAPHY

- [138] Rachel Griffith, Stephen Redding, and John van Reenen. Mapping the Two faces of R&D: Productivity Growth in a Panel of OECD Countries. *Review of Economics and Statistics*, 86:883–895, 2004.
- [139] Z. Griliches. *Price indexes and quality change: Studies in new methods of measurement*. Harvard University Press, 1971.
- [140] Z. Griliches. *Research expenditures and growth accounting*. John Wiley and Sons, New York, 1973.
- [141] Z. Griliches. Issues in Assessing the Contribution of Research and Development to Productivity Growth. *Bell Journal of Economics*, 10(1):92–116, 1979.
- [142] Z. Griliches. *Returns to Research and Development Expenditures in the Private Sector*. Chicago University Press, 1980.
- [143] Z. Griliches. Patent statistics as economic indicators: a survey. *Journal of Economic Literature*, pages 1661–1707, 1990.
- [144] Z. Griliches. Productivity, R&D, and the data constraint. *The American Economic Review*, pages 1–23, 1994.
- [145] Z. Griliches and F. Lichtenberg. Interindustry technology flows and productivity growth: A reexamination. *The Review of Economics and Statistics*, 66(2):324–329, 1984.
- [146] Z. Griliches and F.R. Lichtenberg. *R&D and productivity growth at the industry level: Is there still a relationship?* Chicago University Press, 1984.
- [147] Z. Griliches and J. Mairesse. Productivity and R&D at the Firm Level. In Z. Griliches, editor, *R&D, Patents and Productivity*, pages 339–374. Chicago University Press, 1984.
- [148] Zvi Griliches. The Search for R&D Spillovers. *The Scandinavian Journal of Economics*, pages S29–S47, 1992.
- [149] Zvi Griliches, Ariel Pakes, and Bronwyn H Hall. The value of patents as indicators of inventive activity. Technical report, National Bureau of Economic Research Cambridge, Mass., USA, 1986.

BIBLIOGRAPHY

- [150] E.L. Goshen, A.M. Moyer, A.N. Aizcorbe, R. Bradley, and D.M. Friedman. How government statistics adjust for potential biases from quality change and new goods in an age of digital technologies: A view from the trenches. *Journal of Economic Perspectives*, 31:187–210, 2017.
- [151] G.M. Grossman and E. Helpman. *Innovation and growth in the global economy*. MIT press, 1991.
- [152] G.M. Grossman and E. Helpman. Quality Ladders in the Theory of Growth. *The Review of Economic Studies*, 58(1):43–61, 1991.
- [153] Joonkyung Ha and Peter Howitt. Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory. *Journal of Money, Credit and Banking*, 39(4):733–774, 2007.
- [154] B. Hall and J. Mairesse. Corporate R&D Returns. *Knowledge Economists' Policy Brief*, (6), May 2009.
- [155] Bronwyn H Hall, Jacques Mairesse, and Pierre Mohnen. Measuring the Returns to R&D. Technical report, National Bureau of Economic Research, 2009.
- [156] P. Hanel. R&D, inter-industry and international spillovers of technology and the total factor productivity growth of manufacturing industries in Canada, 1974-1989. *Sherbrooke, Canada: University of Sherbrooke, Cahier de recherche 94-04*, 1994.
- [157] D. Harhoff. R&D and productivity in German manufacturing firms. *Economics of Innovation and New Technology*, 6(1):29–49, 1998.
- [158] R. Harrison, J. Jaumandreu, J. Mairesse, and B. Peters. Does innovation stimulate employment? a firm-level analysis using comparable micro-data from four european countries. *International Journal of Industrial Organization*, 35:29–43, 2014.
- [159] R. Harrod. An Essay in Dynamic Theory. *Economic Journal*, 49(194):14–33.
- [160] E. Helpman and M. Trajtenberg. *General purpose technologies and economic growth*, chapter A time to sow and a time to reap: Growth based on general purpose technologies, pages 55–83. Cambridge, MA, MITPress, 1998.
- [161] R. Henderson, A.B. Jaffe, and M. Trajtenberg. Universities as a source of commercial technology: A detailed analysis of university patenting, 1965-1988. *Revue of Economy and Statistics*, 80:119–127, 1998.

BIBLIOGRAPHY

- [162] H. Hernandez, F. Hervás, and A. Tuebke. The 2011 EU Industrial R&D investment Scoreboard. *European Commission, DG Joint Research Center, IPTS Working Papers, JRC67197*, 2011.
- [163] K. Hirano and Imbens G.W. *The propensity score with continuous treatments*. Wiley, Chichester, 2004.
- [164] B. Holmstrom. Moral hazard in teams. *The Bell Journal of Economics*, pages 324–340, 1982.
- [165] P. Howitt. Steady Endogenous Growth with Population and R&D inputs Growth. *Journal of Political Economy*, 104(4):715–730.
- [166] P. Howitt and Mayer-Foulkes D. R&D, Implementation and Stagnation: A Schumpeterian Theory of Convergence Clubs. Technical report, NBER Working Paper No. 9104, August, 2002.
- [167] Peter Howitt. Endogenous Growth and Cross-Countries Income Differences. *American Economic Review*, 90:829–46, 2000.
- [168] I3U. The State of The European Innovation Union and Working of the European Innovation Systems. *I3U policy brief*, September 2018, 2018.
- [169] I3U. Report on the State of European Innovation Union, Including and Analysis of the 34 Commitments, and the Working of the Innovation Systems. *I3U project deliverable D9.4*, 2019.
- [170] N. Islam. What Have We Learnt From The Convergence Debate? *Journal of Economic Surveys*, 17(3).
- [171] N. Islam. Growth Empirics: A Panel Data Approach. *Quarterly Journal of Economics*, 110:1127–1170, 1995.
- [172] A. Jaffe. Demand and supply influences in R&D intensity and productivity growth. *Review of Economics and Statistics*, LXX(3):431–37, 1988.
- [173] A. Jaffe. Real effects of academic research. *American Economic Review*, 79(5):957–70, 1989.
- [174] A. Jaffe and Trajtenberg. *Patents, Citations and Innovations: A Window on the Knowledge Economy*. MIT Press, 2002.
- [175] Beata Smarzynska Javorcik. Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers Through Backward Linkages. *The American Economic Review*, 94(3):605–627, 2004.

BIBLIOGRAPHY

- [176] D.K.N. Johnson. The OECD Technology Concordance (OTC): Patents by Industry of Manufacture and Sector of Use. *OECD Science, Technology and Industry Working Papers*, 2002.
- [177] D.K.N. Johnson and R.E. Evenson. Innovation and Invention in Canada. *Economic Systems Research*, 9(2):177–92, 1997.
- [178] Charles I Jones. Time Series Tests of Endogenous Growth Models. *The Quarterly Journal of Economics*, pages 495–525, 1995.
- [179] Charles I Jones. Growth: With or without scale effects? *American Economic Review*, pages 139–144, 1999.
- [180] C.I. Jones. R & D-based models of economic growth. *Journal of Political Economy*, pages 759–784, 1995.
- [181] C.I. Jones and P. Romer. The New Kaldor Facts: Ideas, Institutions, Population, and Human Capital. *American Economic Journal: Macroeconomics*, 2:224–245, 2010.
- [182] C.I. Jones and J.C. Williams. Measuring the Social Return to R&D. *The Quarterly Journal of Economics*, 113(4):1119, 1998.
- [183] LE Jones. Technology (and Policy) Shocks in Models of Endogenous Growth. 1999.
- [184] D.W. Jorgenson and Z. Griliches. The explanation of productivity change. *The Review of Economic Studies*, 34(3):249–283, 1967.
- [185] D.W. Jorgenson, M.S. Ho, and K.J. Stiroh. A retrospective look at the US productivity growth resurgence. *The Journal of Economic Perspectives*, 22(1):3–24, 2008.
- [186] D.W. Jorgenson and Stiroh. Raising the speed limit: US economic growth in the information age. *Brookings papers on economic activity*, 2000(1):125–235, 2000.
- [187] Boyan Jovanovic and Peter L Rousseau. General Purpose Technologies. *Handbook of economic growth*, 1:1181–1224, 2005.
- [188] N. Kaldor. A Model of Economic Growth. *The Economic Journal*, 67(268):591–624.
- [189] N. Kaldor. *Capital Accumulation and Economic Growth*. New York: St. Martins Press, 1961.

BIBLIOGRAPHY

- [190] Morton I. Kamien and Nancy L. Schwartz. Timing of Innovation Under Rivalry. *Econometrica*, 40:43–60, 1972.
- [191] Morton I. Kamien and Nancy L. Schwarz. On the Degree of Rivalry for Maximum Innovative Activity. *The Quarterly Journal of Political Economics*, 90:245–260, 1976.
- [192] d’Artis Kancs and Boriss Siliverstovs. R&d and non-linear productivity growth. *Research Policy*, 46:634–646, 2016.
- [193] T.J. Klette. R&D, scope economies, and company structure: a ‘not so fixed effect’ model of plant performance. *Oslo, Norway: Central Bureau of Statistics Discussion Paper No. 20*, 1994.
- [194] T.J. Klette and S. Kortum. Innovating Firms and Aggregate Innovation. *Journal of Political Economy*, 112:986–1018, 2004.
- [195] A.K. Klevorick, R.C. Levin, R.R. Nelson, and S.G. Winter. On the sources and significance of interindustry differences in technological opportunities. *Research Policy*, 24:185–205, 1995.
- [196] T.C. Koopmans. *On the Concept of Optimum Growth*. Chicago: Rand-McNally, 1965.
- [197] Samuel Kortum. Equilibrium R&D and the Patent–R&D Ratio: US Evidence. *The American Economic Review*, pages 450–457, 1993.
- [198] Samuel S Kortum. Research, Patenting, and Technological Change. *Econometrica: Journal of the Econometric Society*, pages 1389–1419, 1997.
- [199] A.M. Kowalski, T. Napiorkowski, V. Vuckovic, N. Cuckovic, A. Karbovski, M.A. Weresa, A. Karbowski, and G. Michalski. ERA-EU-funds - State of implementation and direct impact assessment. *I3U project deliverable D2.2*, 2016.
- [200] P.R. Krugman. The age of diminished expectations: US economic policy in the 1990s, 1994.
- [201] P.K. Kruse-Andersen. Testing R&D Based Endogenous Growth Models. *Copenhagen Institute of Economics Discussion Paper*, 17-05, 2017.
- [202] S. Kuznets. *Economic Growth of Nations*. Cambridge, MA: Harvard University Press, 1971.
- [203] H.U. Kwon and T. Inui. R&D an Productivity Growth in Japanese Manufacturing Firms. *Economic and Social Research Institute (ESRI) Discussion paper series*, 044, December 2003.

BIBLIOGRAPHY

- [204] Christopher A Laincz and Pietro F Peretto. Scale Effects in Endogenous Growth Theory: An Error of Aggregation Not Specification. *Journal of Economic Growth*, 11(3):263–288, 2006.
- [205] Boris Le Hir. *Capturing Information and Communication Technologies as a General Purpose Technology*. PhD thesis, Ecole Centrale, Paris, 2012.
- [206] P. Le Mouel, B. Boitier, and P. Zagame. Impact assessment of IU commitments as a whole. *I3U project deliverable D10.5*, 2019.
- [207] P. Le Mouel, B. Boitier, and P. Zagame. Impact Assessment of IU Commitments Individually and by Groups. *I3U Research project deliverable D10.4*, 2019.
- [208] P. Le Mouel, B. Boitier, and P. Zagame. Sensitivity analysis. *I3U project deliverable D10.6*, 2019.
- [209] P. Le Mouel, B. Le Hir, A. Fougeyrollas, P. Zagame, and B. Boitier. Toward a macro-modelling of European Innovation Union: The contribution of NEMESIS model. In *9th Conference on Model-based Evidence on Innovation and DEvelopment (MEIDE) 16-17 June 2016 Moscow, Russia*, 2016.
- [210] Pierre Le Mouel. Overall impact of the Innovation Union progress as measured in the IU scoreboard. *I3U deliverable D8.2*, 2017.
- [211] D. Lebow and J.B. Rudd. Measurement Error in the Consumer Price Index: Where Do We Stand? *Journal of Economic Literature*, 41:159–201, 2003.
- [212] P. Lecca and S. Sakkas. RHOMOLO V3: A Spatial Modelling Framework. *JRC Technical Reports 111861, Publication Office of the European Union, Luxembourg*, 2018.
- [213] T. Lee and L.L. Wilde. Market Structure and Innovation: A Reformulation. *Quarterly Journal of Economics*, 94:429–436, 1980.
- [214] Aija Leiponen and Ina Drejer. What Exactly are Technological Regimes?: Intra-industry Heterogeneity in the Organization of Innovation Activities. *Research Policy*, 36(8):1221–1238, 2007.
- [215] Richard C Levin, Alvin K Klevorick, Richard R Nelson, Sidney G Winter, Richard Gilbert, and Zvi Griliches. Appropriating the returns from industrial research and development. *Brookings papers on economic activity*, pages 783–831, 1987.

BIBLIOGRAPHY

- [216] Chol-Wong Li. Endogenous vs. Semi-endogenous Growth in a Two R&D-Sector Model. *The Economic Journal*, 100:C110–C122, 2000.
- [217] F.R. Lichtenberg. *R&D investment and international productivity differences*. 1993.
- [218] F.R. Lichtenberg and Siegel D.S. The impact of R&D investment on productivity- New evidence using linked R&D-LRD data . *Economic Inquiry*, XXIX:203–228, 1991.
- [219] A.N. Link. Basic research and productivity increase in manufacturing: Some additional evidence. *American Economic Review*, 71(5):1111–1112.
- [220] A.N. Link. *A disaggregated analysis of industrial R&D: product versus process R&D*. Lexington, MA: D.C. Heath, 1982.
- [221] A.N. Link and J. Rees. Firm size, university based research, and the returns to R&D. *Small Business Economics*, 2:25–31, 1990.
- [222] R.G. Lipsey, K. Carlaw, and C. Bekar. *Economic Transformations: General Purpose Technologies and Sustained Economic Growth*. New York: Oxford University Press, 2006.
- [223] J Lopez and J Mairesse. Influences des Investissements en TIC et R&D sur la Productivité: Une Analyse Empirique sur un Panel Non-Stationnaire. In *2nd ICTNET Workshop, London*, pages 11–12, 2011.
- [224] G. Loury. Market Structure and Innovation. *Quarterly Journal of Economics*, 93:395–410, 1979.
- [225] R. Lucas. On the Mechanics of Economic Development. *Journal of Monetary Economics*, 22(1):3–42, 1988.
- [226] M. Mackiewicz, S. Richter, B. Ecker, and H. Vidovic. State of implementation and direct impact assessment. *I3U project deliverable D6.2*, 2018.
- [227] A. Maddison. *Phases of Capitalist Development*. Oxford University Press, 1982.
- [228] Jakob B. Madsen. Semi-Endogenous Growth versus Schumpeterian Growth Models: Testing the Knowledge Production Function Using International Data. *Journal of Economic Growth*, 13:1–26, 2008.

BIBLIOGRAPHY

- [229] J. Mairesse and B. Hall. *Estimating the productivity of R&D in French and U.S. manufacturing firms: An exploration of simultaneity issues with GMM*. Amsterdam: Elsevier-North Holland, 1994.
- [230] Jacques Mairesse and Pierre Mohnen. Using Innovation Surveys for Econometric Analysis. *Handbook of the Economics of Innovation*, 2:1129–1155, 2010.
- [231] N. Mankiw, P. Romer, and D. Weil. A contribution to the empirics of economic growth. *Quarterly Journal of Economics*, 107:407–37, 1992.
- [232] Stefan Mann. *Sectors Matter Exploring Mesoeconomics*. Springer, 2011.
- [233] E. Mansfield. Basic research and productivity increase in manufacturing. *American Economic Review*, 770:863–873, 1980.
- [234] E. Mansfield. Academic Research and Industrial Innovation. *Research Policy*, 20:1–12, 1991.
- [235] E. Mansfield. Academic research underlying industrial innovations: Sources, characteristics and financing. *Revue of Economics and Statistics*, 77:55–65, 1995.
- [236] E. Mansfield, J. Rapoport, S. Schnee, S. Wagner, and M. Hamburger. *Research and development in the Modern Corporation*. New York: W.W. Norton, 1971.
- [237] E. Maskin and J. Tirole. A theory of dynamic oligopoly, III Cournot competition. *European Economic Review*, 31(4):947–968, 1987.
- [238] E. Maskin and J. Tirole. A theory of dynamic oligopoly, I: Overview and quantity competition with large fixed costs. *Econometrica: Journal of the Econometric Society*, pages 549–569, 1988.
- [239] M. Mazzucato and C. Penna. Beyond market failures: the market creating and shaping roles of state investment banks. *Journal of Economic Policy Reform*, 19:305–226, 2016.
- [240] H. Meijers and B. Verspagen. Construction of Technology Flow Matrices. *DEMETER 7th FP Project, Working Paper No. 1.2a*, 2010.
- [241] Pierre Mohnen. Report on proposal for modifying the NEMESIS model, based on the analysis of the European innovation and the analysis of the 34 commitments. *I3U project deliverable D9.2*, 2018.

BIBLIOGRAPHY

- [242] D. Mowery. *The practice of technology policy*. Blackwell Publisher Inc Cambridge MA.
- [243] F. Narin, K.S. Hamilton, and D. Olivastro. The increasing linkage between U.S. technology and public science. *Research Policy*, 26:317–330, 1997.
- [244] Terleckyj N.E. Direct and indirect effects of industrial research and development on the productivity growth of industries. In J.N. Kendrick and B.N. Vacara, editors, *New Developments in Productivity Measurement and Analysis*, pages 359–386. University of Chicago Press, 1980.
- [245] R. Nelson and S. Winter. In Search of a Useful Theory of Innovation. *Research Policy*, 6:36–77, 1977.
- [246] R.R. Nelson. The simple economics of basic scientific research. *Journal of Political Economy*, 67:297–306, 1959.
- [247] R.R. Nelson. Institutions supporting technical advance in industry. *American Economic Review*, 76:186–189, 1986.
- [248] R.R. Nelson. *National innovation systems: a comparative analysis*. Oxford University Press, USA, 1993.
- [249] R.R. Nelson. Reflections on "The Simple Economics of Basic Scientific Research": Looking Back and Looking Forward. *Industrial Corporate Change*, 15:903–917, 2006.
- [250] T. Niebel, M. O'Mahony, and M. Saam. The contribution of intangible assets to sectoral productivity growth in the EU. Technical report, ZEW Discussion Papers 13-062, 2013.
- [251] P. Nightingale. A cognitive theory of innovation. *Research Policy*, 27:689–709, 1998.
- [252] W. Nordhaus. Do real wage and output series capture reality? The history of lighting suggests not, 1997.
- [253] OECD. *Effective Innovation Policies*. 2015.
- [254] S.D. Oliner and D.E. Sichel. The resurgence of growth in the late 1990s: is information technology the story? *The Journal of Economic Perspectives*, 14(4):3–22, 2000.
- [255] S.D. Oliner, D.E. Sichel, and Board of Governors of the Federal Reserve System (US). *Information technology and productivity: where are we now and where are we going?* Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board, 2002.

BIBLIOGRAPHY

- [256] S.D. Oliner, D.E. Sichel, J.E. Triplett, and R.J. Gordon. Computers and output growth revisited: how big is the puzzle? *Brookings Papers on Economic Activity*, 1994(2):273–334, 1994.
- [257] M O’Mahony and F Peng. Workforce Training, Intangible Investments and Productivity in Europe: Evidence from EU KLEMS and the EU LFS. Technical report, SERVICEGAP Discussion Paper, 2010.
- [258] M. O’Mahony and M. Vecchi. Quantifying the impact of ICT capital on output growth: a heterogeneous dynamic panel approach. *Economica*, 72(288):615–633, 2005.
- [259] R. Ortega-Argiles, M.C. Piva, and M. Vivarelli. Productivity gains from r&d investment: Are high-tech sectors still ahead? *Economics of Innovation and New Technology*, 24:2014–222, 2015.
- [260] Howitt P. Endogenous Growth, Productivity and Economic Policy: A Progress Report. *International Productivity Monitor*, 8, Spring 2004, 2004.
- [261] European Parliament. Lisbon European Council 23 and 24 March 2000, Presidency Conclusions. *European Parliament Website*, 2000.
- [262] L.L. Pasinetti. *Structural Change and Economic Growth*. University Press, Cambridge, 1981.
- [263] L.L. Pasinetti. *Structural Economic Dynamic: A Theory of the Economic Consequences of Human Learning*. Cambridge University Press, 1993.
- [264] K. Pavitt. What makes basic research economically useful? . *Research Policy*, 20:109–119.
- [265] K. Pavitt. The social shaping of the national science base. *Research Policy*, 27:793–805, 1998.
- [266] Pietro F Peretto. Technological change and population growth. *Journal of Economic Growth*, 3(4):283–311, 1998.
- [267] C. Perez. Structural change and assimilation of new technologies in the economic and social systems* 1. *Futures*, 15(5):357–375, 1983.
- [268] B. Peters, B. Dachs, M. Dunser, M. Hud, C. Kohler, and C. Rammer. Firm Growth, Innovation and the Business Cycle. Technical report, Background Report for the 2014 Competitiveness Report, European Commission, May, 2014.
- [269] Edmund S. Phelps. Phillips Curves, Expectation of Inflation and Optimal Unemployment Over Time . *Economica*, 34(135):254–281, 1967.

BIBLIOGRAPHY

- [270] Michael Polder, George van Leeuwen, Pierre Mohnen, and Wladimir Raymond. Product, Process and Organizational Innovation: Drivers, Complementarity and Productivity Effects. *CIRANO-Scientific Publications 2010s-28*, 2010.
- [271] E. Poole and J.-T. Bernard. Defense innovation stock and total factor productivity growth. *Canadian Journal of Economics*, 25(2):438–52, 1992.
- [272] PPMI. Assessment of the union added value and the economic impact of the eu framework programmes - final report. Technical report, 2017.
- [273] Veugelers R. Undercutting the Future? European Research Spending in Times of Fiscal Consolidation. Technical report, Bruegel Policy Contribution, 2014.
- [274] F. Raines. The impact of applied research and development on productivity. *Washington University Wp 6814*, 1968.
- [275] F. Ramsey. A Mathematical Theory of Saving. *Economic Journal*, 28(112):543–59, 1928.
- [276] D.J. Ravenscraft and F.M. Scherer. The Lag Structure of Returns to Research and Development. *Applied Economics*, 14:603–620, 1982.
- [277] J. Ravet, B. Boitier, M. Grancagnolo, P. Le Mouel, L. Stirbat, and P. Zagame. The Shape of the Things to Come: Ex-ante Assessment of the Economic Impact of Horizon Europe. *Journal for Research and Technology Policy Evaluation*, forthcoming, 2019.
- [278] Sergio Rebelo. Long-Run Policy Analysis and Long-Run Growth. *The Journal of Political Economy*, 99(3):500–21, 1991.
- [279] J.F. Reinganum. *The Timing of Innovation: Research, Development and Diffusion*, volume 1. New York: North-Holland, 1989.
- [280] Wieser Robert. Research and Development Productivity and Spillovers: Empirical Evidence at the Firm Level. *Journal of Economic Surveys*, 19(4):587–621, 2005.
- [281] Werner Roeger and Janos Varga. Structural Reforms in the EU: A Simulation-Based Analysis Using the QUEST Model with Endogenous Growth. Technical report, Directorate General Economic and Monetary Affairs (DG ECFIN), European Commission, 2008.

BIBLIOGRAPHY

- [282] P. Romer. Growth Based on Increasing Returns Due to Specialization. *The American Economic Review*, 77(2):56–62, 1987.
- [283] P.M. Romer. Increasing returns and long-run growth. *The Journal of Political Economy*, 94(5):1002, 1986.
- [284] P.M. Romer. Endogenous technological change. *Journal of Political Economy*, 98(S5):71, 1990.
- [285] C. Rosemberg, M. Wain, P. Simmonds, B. Mahieu, and K. Farla. Ex-post evaluation of Ireland’s participation in the 7th Framework Programme . *Final Report, Technopolis Group, June*, 2016.
- [286] N. Rosenberg. Why do firms do basic research (with their own money). *Research Policy*, 19:165–174, 1990.
- [287] Felix Roth and Anna-Elisabeth Thum. Does Intangible Capital Affect Economic Growth? *CEPS Working Documents*, (335), 2010.
- [288] N. Sakurai, E. Ioannidis, and G. Papaconstantinou. The Impact of R&D and Technology Diffusion on Productivity Growth - Evidence of 10 OECD Countries in the 1970s and 1980s, 1996.
- [289] M. Sanchez-Martinez, P. Benedetti-Fasil, C., Christensen, and N. Robledo-Bottcher. R&D tax credits and their macroeconomic impact in the EU: an assessment using QUEST III. *JRC Technical Reports - EUR 28858 EN*, 2017.
- [290] F.M. Scherer. *Using linked patent and R&D data to measure interindustry technology flows*. University of Chicago Press, Chicago.
- [291] F.M. Scherer. Inter-industry technology flows and productivity growth. *The Review of Economics and Statistics*, 64(4):627–634, 1982.
- [292] F.M. Scherer. Concentration, R&D and productivity change. *Southern Economic Journal*, 50:221–225, 1983.
- [293] J.A. Schumpeter. *Business Cycles: a Theoretical, Historical and Statistical Analysis of the Capitalist Process*, volume 100. Cambridge University Press, 1939.
- [294] J.A. Schumpeter. *Capitalism, Socialism and Democracy*. New York, 1942.
- [295] Paul Segerstrom. Endogenous Growth without Scale Effects. *American Economic Review*, 88(5):1290–1310, 1998.

BIBLIOGRAPHY

- [296] Karl Shell. *"Inventive Activity, Industrial Organization and Economic Growth"*. London: Macmillan and New York: Halsted (John Wiley & Sons), 1973.
- [297] Andrew Sissons. *More than Making Things: A New Future for Manufacturing in a Service Economy*. *Work Foundation, London*, 2011.
- [298] R. Solow. *Growth Theory: An Exposition*. New York: Oxford University Press, 1970.
- [299] R. Solow. Growth Theory and After. *The American Economic Review*, 78:307–17, 1988.
- [300] R.M. Solow. A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, pages 65–94, 1956.
- [301] R.M. Solow. Technical change and the aggregate production function. *The Review of Economics and Statistics*, 39(3):312–320, 1957.
- [302] R.M. Solow. We'd better watch out. *New York Times Book Review*, 12(13), 1987.
- [303] Martin Srholec and Bart Verspagen. The Voyage of the Beagle into Innovation: Explorations on Heterogeneity, Selection, and Sectors. *Industrial and corporate change*, 21(5):1221–1253, 2012.
- [304] A. Sterlacchini. R&D, innovation and total factor productivity growth in British manufacturing. *Applied Economics*, 21:1549–1562, 1989.
- [305] Kevin Stiroh. Reassessing the Impact of IT in the Production Function: a Meta-Analysis. *Federal Reserve Bank of New York, mimeo*, 2002.
- [306] T.W. Swan. Economic Growth and Capital Accumulation. *Economic Record*, 32, 1956.
- [307] Quah D. T. Convergence Empirics Across Economies with (Some) Capital Mobility. *Journal of Economic Growth*, March, 1996.
- [308] N.E. Terleckyj. Effects of R&D on the productivity growth of industries: an explanatory study. *Washington, D.C.: National Planning Association*.
- [309] M. Timmer, T. van Moergastel, E. Stuivenwold, G. Ypma, M. O' Mahony, and M. Kangasniemi. EU KLEMS growth and productivity accounts. *Gronigen Growth and Development Centre, University of Gronigen*, 2007.

BIBLIOGRAPHY

- [310] Marcel P Timmer, Abdul Azeez Erumban, Bart Los, Robert Stehrer, and Gaaitzen de Vries. Slicing Up Global Value Chains. In *32nd General Conference of The International Association for Research in Income and Wealth, Boston, USA*, 2012.
- [311] J. Tirole. *The theory of industrial organization*. MIT press, 1994.
- [312] A.A. Toole. The impact of public basic research on industrial innovation: Evidence from the pharmaceutical industry. *Research Policy*, 41:1–12, 2012.
- [313] M. Trajtenberg. Innovation in Israel 1968-1997: a comparative analysis using patent data. *Research Policy*, 30:363–389, 2001.
- [314] M. Trajtenberg, R. Henderson, and A. Jaffe. University versus corporate patents: A window on the basicness of invention. *Economics of Innovation and New Technology*, 5(1):19–50, 1997.
- [315] H. Ulku. R&D, Innovation and Growth: Evidence from Four Manufacturing Sectors in OECD. *Oxford Economic Papers*, 2007.
- [316] B. van Ark, M. O'Mahony, and M.P. Timmer. The productivity gap between Europe and the United States: Trends and causes. *Journal of Economic Perspectives*, 22(1):25–44, 2008.
- [317] R. van Elk, B. Verspagen, B. ter Weel, K. van der Wiel, and B. Wouterse. A macroeconomic assessment of the returns to public R&D investments. *CPB Discussion paper No. 313*.
- [318] H. van Meijl. Measuring Intersectoral Spillovers: French Evidence. *Economic Systems Research*, 1997.
- [319] B. van Pottelsberghe de la Potterie. Issues in Assessing the Impact of Interindustry R&D Spillovers. *Economic Systems Research*, 9(4):331–56, 1997.
- [320] John Van Reenen, Nicholas Bloom, Mirko Draca, Tobias Kretschmer, Raffaella Sadun, Henry Overman, and Mark Schankerman. The Economic Impact of ICT. Technical report, Final Report for the European Commission, 2010.
- [321] Janos Varga. *The QUEST III DSGE Model*. Palgrave Macmillan, 2019.
- [322] J. Vargs, W. Roeger, and J. Veld. Growth Effects of Structural Reforms in Southern Europe: the case of Greece, Italy, Spain and Portugal. *Empirica*, 41(2):323–363, 2014.

BIBLIOGRAPHY

- [323] E. Vedung. *Policy instruments: typologies and theories*. Transaction Publishers, London, 1998.
- [324] F. Venturini. Product Variety, Product Quality, and Evidence of Endogenous Growth. *Economic Letters*, 117:74–77, 2012.
- [325] B. Verspagen and I. De Loo. Technology Spillovers between Sectors and Over Time. *Technological Forecasting and Social Change*, 60:215–235, 1999.
- [326] Bart Verspagen. Endogenous Innovation in Neo-Classical Growth Models: A Survey. *Journal of Macroeconomics*, 14(4):631–662, 1992.
- [327] Bart Verspagen. Estimating International Technology Spillovers Using Technology Flow Matrices. *Review of World Economics*, 133(2):226–248, 1997.
- [328] Bart Verspagen, Hugo Hollanders, and Liesben Noben. Conceptualizing the Innovation Systems of the European Union. *I3U deliverable D9.1*, 2017.
- [329] Bart Verspagen, Liesbeth Noben, and Raf Sluismans. Innovation Systems and the Role of Public Policy in the European Innovation Union. *I3u deliverable D9.3*, 2017.
- [330] R. Veugelers and B. Cassiman. R&D cooperation between firms and universities. Some empirical evidence from Belgium manufacturing. *International Journal of Industrial Organization*, 23:355–379, 2005.
- [331] W. Vullings, E. Arnold, Boekholt P., M. Horvat, B. Moestert, and M. Rijnders-Nagle. European Added Value of EU Science, Technology and Innovation Actions and EU-Member States Partnerships in International Cooperation. *Main Report, Technopolis Group*, 2014.
- [332] J.C. Wang and K.H. Tsai. *Productivity Growth and R&D Expenditures in Taiwan’s Manufacturing Firms*. The University of Chicago Press, Chicago/London, 2004.
- [333] Rene Wintjes and Pierre Mohnen. Review of empirical studies on the effectiveness of R&D subsidies: The input and output additionality from national and EU subsidies. *Annex II of “Support for Assessment of Socio-Economic and Environmental Impacts (SEEI) of European R&I Programme: the Case of Horizon Europe”, European Commission KI-02-18-999-EN-N (2018)*., 2018.

BIBLIOGRAPHY

- [334] E.N. Wolf and M.I. Nadiri. Spillovers effects, linkage structure and market competition in Japan. *Structural Change and Economic Dynamics*, 4(2):315–331, 1993.
- [335] Alwyn Young. Growth Without Scale Effects. *Journal of Political Economy*, 106(1):41–63, 1998.
- [336] Paul Zagame, Arnaud Fougeyrollas, and Pierre Le Mouel. Consequences of the 2013 fp7 call for proposals for the economy and employment in the european union. Technical report, SEURECO - DEMETER working paper, 2012.
- [337] S.A. Zahra and G. George. Absorptive capacity : A review, reconceptualization, and extension. *Academic Management Review*, 27:185–203, 2002.
- [338] J. A. Zuniga-Vicente, C. Alonso-Borrego, F. J. Forcadell, and J. I. Galan. Assessing the effect of public subsidies on firms R&D investment: A survey. *Journal of Economic Surveys*, 28, 2012.