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# Capturing Information and Communication Technologies as a General Purpose Technology

Boris Le Hir

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Boris Le Hir. Capturing Information and Communication Technologies as a General Purpose Technology. Other. Ecole Centrale Paris, 2012. English. NNT : 2012ECAP0046 . tel-00997417

**HAL Id: tel-00997417**

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**ÉCOLE CENTRALE DES ARTS  
ET MANUFACTURES  
« ÉCOLE CENTRALE PARIS »**

**THÈSE**  
présentée par

**Boris LE HIR**

pour l'obtention du

**GRADE DE DOCTEUR**

**Spécialité : Sciences Economiques**

**Laboratoire d'accueil : ERASME**

**SUJET :**

**Capturing Information and Communication Technologies  
as a General Purpose Technology**

**soutenue le : 20/11/2012  
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Capturing Information and Communication Technologies as a  
General Purpose Technology

Boris LE HIR



## Remerciements

Je tiens à remercier ici toutes les personnes qui ont contribué à la réalisation de ce travail.

En premier lieu, j'exprime ma profonde et sincère reconnaissance au Professeur Paul Zagamé sans qui l'économie serait certainement restée dans mon esprit *terra incognita* avec la mention "hic sunt dracones". Je le remercie pour avoir accepté de diriger cette thèse et m'avoir permis d'intégrer l'équipe de recherche du laboratoire ERASME de l'Ecole Centrale Paris. Je le remercie aussi pour l'ensemble de son aide et de ses conseils ainsi que de ses encouragements nécessaires à la réalisation de ce travail.

Je tiens à remercier aussi les Professeurs Luc Soete et Jean-Luc Gaffard pour avoir accepté la lourde tâche de rapporteur ainsi qu'au Professeur Gilbert Cette et à Dr. Domenico Rossetti Di Valdalbero pour l'honneur qu'ils me font de participer au jury de cette thèse.

Je souhaite bien entendu remercier chaleureusement tous les membres de l'Equipe ERASME, à la fois pour leurs innombrables conseils, pour le travail de relecture et pour leurs qualités humaines qui ont permis de créer une ambiance favorable aux travaux de recherche. Ces remerciements s'adressent à Pierre Le Mouël, Arnaud Fougeyrollas, Baptiste Boitier, Gilles Koléda et Gabriel Galand. Je remercie aussi Thannaletchimy Thanagopal pour la correction de l'anglais d'une partie de la thèse, les autres thésards du laboratoire ainsi que Danielle Schirmann-Duclos pour son dynamisme.

Je tiens par ailleurs à remercier un ancien doctorant du laboratoire ERASME, Hugo Pillu, pour l'atmosphère chaleureuse que l'on a eu dans notre bureau et pour son expertise sur les données de brevets. Ma reconnaissance s'adresse aussi à d'autres anciens membres du laboratoire, Oualid Gharbi et Arach Hirmanpour, avec lesquels j'ai partagé de bons moments.

Je remercie très sincèrement Florent Pratlong, Gilles Koléda, Constance Monnier ainsi que M. le Professeur Pierre Médan pour leurs aides précieuses dans mes activités d'enseignement à l'Ecole Centrale Paris et à l'Université Paris 1 Panthéon-Sorbonne.

En outre, les travaux qui constituent cette thèse ont été réalisés dans le cadre d'un projet de recherche européen, le projet DEMETER. Je souhaite par conséquent remercier la Commission Européenne et, en particulier, la Direction Générale de la Recherche ainsi que les personnes ayant suivi le projet, Messieurs Pierre Vallette, Daniel Debey et Domenico Rossetti Di Valdalbero.

Dans le cadre de ce projet, mes travaux se sont donc réalisés grâce à la collaboration d'autres chercheurs et équipes de recherches européens dont l'apport intellectuel m'a été précieux. Je tiens, à ce titre, à exprimer ma profonde gratitude au Professeur Dominique Foray pour m'avoir reçu à plusieurs reprises à l'Ecole Polytechnique Fédérale de Lausanne et pour m'avoir orienté et prodigué d'excellents

conseils pour ma recherche. Je remercie de même très sincèrement Julio Raffo avec qui j'ai travaillé sur place et qui m'a accueilli chez lui.

Je souhaite aussi remercier les Professeurs Luc Soete et Bart Verspagen ainsi que Dr. Huub Meijers pour la qualité de leur collaboration dans le cadre ce projet DEMETER et, surtout, pour la construction des matrices de citations de brevets qui m'ont été très utiles. Je tiens également à remercier toutes les personnes qui ont participé à ce projet et avec qui j'ai eu des discussions fertiles lors des réunions de travail. Il s'agit de personnes membres des équipes du Bureau Fédéral du Plan Belge, de l'Université Catholique de Louvain, du E3M lab de l'Université Polytechnique d'Athènes ainsi que de l'UNU-MERIT.

Je suis par ailleurs très reconnaissant envers l'Ecole Centrale Paris et son Ecole doctorale qui a financé ma recherche et je remercie particulièrement Messieurs les Directeurs Jean-Hubert Schmitt et Nasser Darabiha pour m'avoir accordé leur confiance, ainsi que Catherine Lhopital et Géraldine Carbonel pour leur sympathie et leur grande efficacité administrative. Je remercie de même l'Université Paris 1 Panthéon Sorbonne pour mon financement en tant qu'Assistant Temporaire d'Enseignement Recherche.

Par ailleurs, j'exprime mon extrême reconnaissance à Georgina Caspari pour la longue relecture de la thèse et la correction de l'anglais en plein mois d'Août. Je reste néanmoins l'unique responsable des éventuelles fautes contenues dans ce texte.

Je tiens finalement à dire un grand merci à tous mes proches qui m'ont unanimement soutenu tout au long de cette thèse. Je remercie particulièrement mes parents pour tout ce qu'ils ont fait afin que je puisse aboutir dans mes études. Je n'oublie évidemment pas les autres membres de ma famille ainsi que mes amis que je remercie pour leur inestimable appui.

Enfin je remercie Lætitia pour sa grande patience et son soutien pendant ces quelques années.







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# Chapter 1

## General Introduction

### 1.1 Introduction

Economic evolution is largely influenced by technical change in the long term. The idea is relatively old and has been largely developed thanks notably to the works of J.A. Schumpeter (1939 [202], 1942 [203]). More recently, after explaining economic growth through the existence of non-decreasing return (Solow, 1956 [211]; Romer, 1986 [191]), endogenous growth theories provided a formalisation of these economic mechanisms through expected monopoly rents that constitute the returns of research costs (Romer, 1990 [192]; Grossman and Helpman, 1991 [104]; Aghion and Howitt, 1992 [4]). These formalisations brought very valuable tools in the understanding of long term economic growth. However, these theories describe a continuous growth path whereas, in reality, the process of growth is discontinuous and heterogeneous. Indeed, over a century we can observe cycles with different magnitudes and periods which did not take place simultaneously in all regions. Some of these cycles are identified under the names of Juglar (1862 [139]), Kuznets (1930 [145]) or Kondratieff (1926 [141]) cycles by economists according to their average period, the Kondratieff cycle being the longest and the Juglar cycle the shortest. The story of the western economies during the twentieth century shows an acceleration of growth in productivity in the United States during the 1920s. This rapid leap in economic performance was called the “Big Wave” and only reached Europe post-war. Besides, since the first oil shock, even if Europe continued to catching up slowly with the US, both regions underwent a long period of stagnation in productivity until the beginning of the 21<sup>st</sup> century when productivity growth started up again in US.

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Economists have long sought to determine the factors for these successive and non simultaneous waves of growth. Among them, J.A. Schumpeter (1939 [202], 1942 [203]) explains the long term Kondratieff cycles, whose period ranges from 40 to 60 years, by the emergence of major innovations carrying clusters of innovations. Later, economic historians emphasize that some key technologies, such as printing, the steam engine or the dynamo, played a prominent role in these successive waves of innovations that led the process of growth (Landes, 1969 [146] or Rosenberg, 1982 [193]).

The last quarter of the twentieth century saw the emergence and the wide diffusion of a new technology, or rather a set of new technologies known collectively as Information and Communication Technologies (called ICT thereafter), which, at first, generated a lot of hope for economic development. Nevertheless, several years after the start of the “digital revolution”, the economic performances measured did not meet expectations since the growth in productivity stagnated at a relatively low level in most modern economies. Indeed, this “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., but at first, it did not materialize in macroeconomic statistics on growth and productivity. Then, hope gave way to confusion and pessimism. Economists were faced with a productivity paradox as shown by the famous quotation by Solow: “You can see the computer age everywhere but in the productivity statistics”<sup>1</sup>. We can also cite Krugman (1994 [142], p173), whose perplexity was close to pessimism: “Something is out of kilter here. Either the technology isn’t 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”. Worse, some authors even pointed out that non-manufacturing ICT-using industries underwent a labor productivity slowdown. They remark in addition that the main primary impact of ICT was observed in inflation, thereby highlighting the effects of Baumol’s disease (Baumol, 1965 [16]) in non-progressive service industries despite their intensive use of ICT. This observation led Gordon (1998 [89]) to think that “there is something wrong with computers”.

In addition, over the second half of the twentieth century, developed countries experienced a large redeployment of their economic structures from manufacturing industries towards service industries<sup>2</sup>. Thus the extent of standstill productivity growth in these sectors expanded in the economy at the

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<sup>1</sup>Robert Solow in a declaration for the New York Times Book Review, July 12, 1987, p36

<sup>2</sup>Most reasons of this observed shift are summerized in Schettkat and Yocarini (2006 [196]). Among them, we can remind two of the most important: (i) higher income per capita has led to higher demand for services; (ii) the outsourcing of the marketing, trade or transport activities may have impacted the assignment of the output in the statistics.

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macro level.

Others are more nuanced. Oliner et al. (1994 [175]) or Jorgenson and Stiroh (1995 [138]) kept the apparent productivity paradox into perspective and reported a small contribution of computers to growth<sup>3</sup>, but commensurate with the share of computer equipment in the capital stock in the 1980s and early 1990s. They were the first to quantify the impact of ICT using a growth accounting framework<sup>4</sup>.

Looking back on the beginning of the twentieth century and focusing on electricity, the following idea of some economists in industrial innovation is gaining ground (see Freeman and Soete 1982 and 1997 [84, 86]; David, 1990 [67]): the production system must be restructured with the diffusion of new major technologies insomuch as such technologies need time to deploy their full impact.

From the theoretical point of view, on one hand, some economists question the ability of statistics to demonstrate fundamental changes in the nature of the production and trade and to help us to comprehend these type of changes (Nordhaus 1997 [167]). On the other hand, the analysis of the characteristics of major technologies, defined as General Purpose Technologies (henceforth GPT), reveals how these technologies are able to generate clusters of innovations. Their ubiquity and their role as “enabling technology”, “opening up new opportunities rather than offering complete, final solution” (Bresnahan and Trajtenberg, 1995 [31]) appear to be fundamental factors.

Next, the evolution of productivity in the United States during the second half of the 1990s, and especially productivity in intensive ICT using industries, will prove they were right. Besides, in Europe, where ICT use is much lower, the growth in productivity does not ensue and thus corroborates the predominant role of ICT in the US productivity resurgence. So in 2000, as Jorgenson and Stiroh (2000 [137]) point out, the “pessimism of the famous Solow paradox [...] has given way to the optimism of the information age”.

But empirical observations still reserved surprises. Indeed, following the burst of the dotcom bubble in 2000, ICT investments slacked off and suggested to economists that productivity growth should slowdown again over the next several years, but it was not the case in the US. This new paradox again reflected, matter-of-factly, the need for further explanations rather than a simple ICT-centered story. For that purpose, the concept of GPT provides valuable clues.

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<sup>3</sup>0.21% point per year for the period 1980-1992 in Oliner and Sichel (1994) and 0.15% point per year for the period 1985-92 in Jorgenson and Stiroh (1995)

<sup>4</sup>In their study, IT included only computers but not yet communication equipment and software

### 1.2 Motivation

**The concept of General Purpose Technology:** In its article “The dynamo and the computer: an historical perspective of the modern productivity paradox”, David (1990 [67]) depicts how the dynamo has reshaped the production system. In particular, he reminds us that the switch from the steam engine to the electrical drive system paid off only after several stages. Indeed, at first, at the beginning of the twentieth century, the dynamo replaced the steam engine, however the architecture of the production system did not change since it was still driven by a central motor unit and a transmission shaft. Thus, during the first stages of the adoption of this new technology, the production mode remained identical and productivity was not improved, only the energy source changed. It is only in the 20s, after the invention of the unit drive system that the production process could be redesigned and we see the impact on productivity. The effects were then even more important than expected:

“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 [67])

Principally this technology, the dynamo, associated with the unit drive, allowed important new reorganizations of the production process and led to a lot of additional positive impacts. These repercussions were of a varied nature such as (i) savings in fixed capital; (ii) the optimizing of machine placement and, therefore, the reduction in handling operations; (iii) the reduction of losses during maintenance since the intervention on an individual machine becomes possible without shutting down the entire power system; (iv) the implementation of a continuous production process like in chemical industries.

This type of in-depth change of the production process following the adoption of a new technology is defined by Perez (Perez, 1983 [183]; see also Freeman and Perez, 1986 [83]) as a change of techno-economic paradigm. In the case of the computer, we are still probably in the transition period that may lead to such a new techno-economic paradigm.

The concept of General Purpose Technology, theoretically formalized by Bresnahan and Trajtenberg (1995 [31]), offers an attractive conceptual tool to bridge such micro-analysis of radical technical change and its macroeconomic modelling. Especially, it describes the economic mechanisms involved as well as the features that a technology should display in order to implement them. Theoreticians actually

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identify three main GPT properties that are the following (Lipsey et al. 2006 [152])<sup>5</sup>:

1. Initially they present wide possibilities for development;
2. They could be used in various ways and they present possibilities for use in a lot of different sectors;
3. They offer large technological complementarities.

Together, these features set in motion a spiral of interactions between different types of agents that makes a GPT an engine of growth. These interactions appear mainly in the form of externalities.

**General Purpose Technology and externalities** Economic literature attributes a peculiar property to innovations which is that they yield positive externalities involving an incomplete appropriation of innovation return because they benefit other agents rather than their inventors without passing through markets and prices<sup>6</sup>. This inability to capture the total return from innovations thus leads to a suboptimal level of spontaneous research investment and, consequently, to a spontaneous suboptimality of economic growth. Actually, two types of externalities are identified. (i) The first one allows an agent to benefit from research and development (R&D) expenditure through the purchase of a good which is R&D intensive. These externalities are also called “*rent externalities*” or “*market externalities*”<sup>7</sup>. (ii) The second type allows an agent to benefit from R&D expenditure without financial compensation. Externalities of this type are called “*pure knowledge spillovers*”. Griliches (1971 [98], 1979 [99]) theoretically formalized these two types of externalities in the following way. On one hand, rent externalities or market externalities are tied to the purchase of a good which is R&D intensive to a price inferior to the one reflecting its real value. This comes from the fact that inventors cannot appropriate all the rent coming from their innovations. So the consumer benefits from a good with a price that is not fully adjusted for quality improvements. On the other hand, “*Pure knowledge spillovers*” come from the cumulative aspect of knowledge and occur when knowledge produced by a research team is used and then contributes to the innovation process of another research team. Innovations related to a GPT are obviously not spared from these externalities.

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<sup>5</sup>Actually, they identify four features but we group together two of them in the second feature of the list which underlies the ubiquity of the technology.

<sup>6</sup>The notion of knowledge externalities appeared with A Marshall (1920, [156])

<sup>7</sup>As they are often tied to price measurement problems, rent spillovers are often not considered as “real knowledge spillovers” but rather as a measurement errors.



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In addition to these traditional knowledge and rent externalities inherent to most innovations, GPT features create another important externality network between two types of sectors: the GPT producer sector (also called “GPT inventors”) and the GPT using industries (also called “GPT co-inventors” of applications). The involved externalities are described in a detailed way by Bresnahan and Trajtenberg (1995 [31]) and by Bresnahan (2003 [32]) and can be identified in two different ways:

1. A vertical externality between the GPT producer and each user sector in that the basic inventions of GPT generate new opportunities for developing applications in user sectors;
2. A horizontal externality within user sectors which deals with the fact that the more users there are and the larger their demands for the GPT, the larger will be the incentive to invent in the GPT producer sector that, 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 [31]).

This situation is in fact a special case of “*strategic complementarity*” originally established in the game theory framework by Bulow et al. (1985, [41]) which characterizes a situation where decisions by two or more players reinforce the other players.

This externality structure creates a lot of inertia and coordination problems in the system: when things evolve favorably, a long term dynamic develops consisting of large-scale efforts in research activities whose social and private marginal returns attain high levels. In the other case, the system is likely to become trapped into a very low level of research investment in both types of sectors. This externality structure logically creates several delays: between “invention” and first “co-invention”; between “co-invention” and further investment in the basic invention and the generalization of “co-invented ideas”.

Such a theoretical specification calls for some comments: (i) The first is that the three GPT properties enumerated above are “techno-centered” whereas the externalities relate to relationships between economic agents belonging to different economic sectors that are either the sector of production or sectors of use of the GPT. The main interest of such an approach is thus to do the techno-economic bridge. (ii) The second remark is that, while the three GPT features are inherent to a GPT, the externalities they yield, and especially the magnitude of these externalities, are conditioned by the structural environment. Therefore, the diffusion of a GPT may induce a more or less buoyant and powerful force on economic growth depending on the environment. In order to achieve the full power

of the engine, the economic environment must be not only conducive to the diffusion of the GPT but also to the development of complementary innovations enabled by the previous externalities.

**Information and Communication Technologies as General Purpose Technology** In view of the description of the concept of GPT, we can note that considering ICT as GPT as several implications:

1. The first is that, in this way, we do not focus on a technology but rather on a set of technologies as a whole. Nevertheless, this approach is relevant for the reason that all these technologies are applied for one objective: the manipulation of information. Moreover, the term technology refers to the application of scientific knowledge for practical purposes. So that we distinguish technologies with respect to their practical purposes and, as we just said, the only purpose is the manipulation of information. Furthermore, the set of ICTs groups together the three components of the digital information world that work together towards this goal. These three components are: electronic circuits; mass memory and networks<sup>8</sup>. We can note also that each of them permits the performance one of the three tasks for the information manipulation: data processing, storage and transmission.<sup>9</sup>
2. The second implication of considering ICT as GPT is that ICT must verify all the GPT features mentioned above and this is not obvious. More concretely, in order to consider ICT as GPT:
  - (a) ICT must highlight wide potential for development, corresponding to a more generalized Moore's law<sup>10</sup>;
  - (b) There must be a widespread use of ICT across sectors;
  - (c) As a GPT offers large technological complementarities in downstream sectors, we must show that innovation and adoption of ICT lead to an increase in innovations or innovation activities in user sectors. This feature is actually the most important, but also the most difficult to prove since, as we will see induced innovations as well as the factors of such innovations take on very different forms.

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<sup>8</sup>see G. Berry (2008, [22]). In addition, depending on our approach, we will also add programs.

<sup>9</sup>Actually, the case of the dynamo may be considered similarly, in the sense that it was not only the dynamo that made the revolution but the set of inventions that allowed the production, transmission and conversion of energy on an increasingly large scale.

<sup>10</sup>Moore's law is a paradigm describing exponential growth in computing, pointing out that the number of transistors on integrated circuits doubles approximately every two years.

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In the case of ICT, the externality structure described above has been particularly strong and powerful in activities like scientific instrument or industrial design where specific circumstances created a very favorable environment for the co-invention of applications, which in turn generated virtuous feedback loops in the system. In such circumstances, the externalities between inventors of ICTs and co-inventors of applications are considerable. For some other activities, such as services, the whole dynamic did not work so well. As we have already mentioned in the first section of this introduction, this has been the case particularly in Europe, where highly ICT intensive services experienced low labor productivity growth and showed the symptom's of Baumol's disease.

**Policy assessment:** However, non-progressive sectors can become progressive, Baumol's disease can be cured, if certain structural problems dealing with the conditions and procedures of knowledge production and use are solved. There are actually very few sectors that are inherently non progressive (in the sense that, like the performing arts, by their very nature, these activities permit only sporadic increases in productivity) but most non progressive sectors are structurally non progressive; i.e. they can become progressive if structural problems are solved. Actually, Triplett and Bosworth (2006 [220]), among others, have documented that Baumol's disease has been cured in US service industries.

It is thus suggested simulating and evaluating policies targeting some of the service industries in order to increase the intensity of innovative activities in these sectors, thereby, stimulating the co-invention of applications. However, as such a policy aims to support the "diffusion" of a GPT, serious coordination problems may arise from the innovational complementarities that characterize the dynamics of a GPT. Any policy that increases the rate of co-invention of applications in user sectors generates a positive demand response which creates more opportunities for the producer sector by enlarging the market: creating more invention on the producer and user sides. It is, therefore, attractive to think of using the structural micro-level incentives created by these complementarities to amplify the positive feedback effects of any policy intervention (targeting user sectors) in order to propel the whole economy, or any large subset of these sectors (producers and users), therefore, to develop a new techno-economic trajectory (Aghion, David and Foray, 2009 [3]).

The awareness of the information society issue, which began several decades ago in a few countries, is growing and spreads throughout governments and public institutions. At the 2000 Lisbon Summit, Europe already defined ICT as a major issue. More recently, in order to ensure the continuance of the Lisbon Strategy, the European Union established, in March 2010, the Europe 2020 Strategy of

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which one of the key programs is the European Digital Agenda (European Commission, 2010 [55]). At the world level, the increase in the digital divide separating rich countries from poor countries alarmed international institutions and, in 2003, the International Telecommunication Union (ITU) and the United Nations (UN) organized the first World Summit of the Information Society (WSIS), which took place in Geneva for the first phase and in 2005 in Tunis for its second phase. This summit recognized the importance of the role that ICT could play in the reduction of inequalities and also defined a Plan of Action (Geneva, 2003 [177]) as well as a Digital Agenda (Tunis Agenda, 2005 [178]). The approach adopted in this thesis may provide valuable tools for assessing such policies and we will show, in particular, that policies focused solely on the diffusion of ICT and on innovation in this sector could be insufficient or a too restrictive answer.

**Objectives:** The aims of this thesis are threefold:

- The first objective is to capture the GPT properties of ICT and, in this way, empirically confirm the general purpose nature of these technologies;
- The second objective is to provide precise indications on the way we can model interactions between GPT producers and users;
- Finally, the third objective is to explain the weakness of labor productivity growth in Europe compared to the US in the light of GPT mechanisms.

Actually, these three objectives are very closely linked. Indeed, we will see that a large part of the European lag comes from its weak capability to harness the GPT properties of the ICTs and to improve coordination between ICT producers, as well as between producers and users, to absorb the positive externalities that arise from these GPT properties.

Therefore, as we will study the “European problem” from the perspective of a possible malfunction of GPT-related mechanisms and as these mechanisms are strongly linked to GPT properties, we will organize this thesis around them.

The main difficulties that we have to confront, in order to fulfill these objectives, rest on the identification of the way to capture the GPT properties of ICT. GPT features are especially difficult to grasp in a detailed way because they take several different paths, such as knowledge externalities or strategic complementarities, that are neither totally separate nor totally linked. Indeed, depending on the feature and the sector, a particular mechanism may be involved. For instance, knowledge

externality may be the most significant interaction between certain sectors such as *ICT industries* and *Health services* or *Non-ICT electrical goods*, whereas between other sectors such as *ICT industries* and *Wholesale and retail trade* or *Finance and insurance*, the most significant interaction may consist in “purely innovation complementarities”. Furthermore, innovation activities may also take different forms. Among them, R&D expenditures are the most visible but all other expenditures aiming to enhance the economic performance by, for instance, improving organization or human capital should also be taken into account as innovative activities.

Finally, the work done here will clarify the debate and identify both the mechanism corresponding to each feature and type of sector as well as the way they appear in the economic data. It will also lead to recommendation for future implementation of these mechanisms in macro-economic models in order to provide reliable tools for GPT/ICT oriented policy assessments.

### 1.3 Overview

This thesis is organized around the three GPT characteristics and the way to capture them. So, this document consists of three parts, each part corresponding to one of the GPT features described above.

In the first part of this thesis, we deal especially with the pace of development of ICT. After a quick review of ICT history, we first study data on innovation in the field of ICT. Next, in chapter 3, we discuss the economic measurement problems that emerge in the field of ICT. These problems are especially inherent to the emergence of new major technologies or due to an unusual technical progress.

The second part deals with the ubiquitous nature of ICT. The first chapter of this part describes, on one hand, the diffusion of ICT capital over time, country and economic sectors and, on the other hand, it conducts a review of the literature that assesses the direct economic impact of ICT diffusion using a growth accounting framework. In the second chapter, we try to identify production behaviour, in terms of the factors demand, in ICT producing and intensive using industries. We study whether the production is better optimized in some countries. In that chapter, we also seek for evidence of externalities of ICT adoption.

The last part deals with the most specific and important feature of a GPT, which is the ability to create large innovation possibilities in downstream sectors. After outlining the mechanisms involved, we depict the way to define co-inventions and we provide empirical evidence of their complementarity with ICT innovations.

## Part I

# Technological Progress in ICT



## Chapter 2

# Innovation in ICT industries

### 2.1 Introduction

In 1965, a semiconductor engineer and a future co-founder of Intel, Gordon Moore, observed that the number of components in integrated circuits had doubled every year and predicted that it would continue for at least ten years. Ten years later, this was verified. Then he revised his prediction in 1975 and declared that the number of transistors in microprocessors would continue to double every two years. In fact, this exponential rate of growth did not begin with the invention of integrated circuits in 1958. Indeed, R Kurzweil<sup>1</sup> showed that we have observed exponential growth in computing power for more than one hundred years and, even, this exponential trend may have accelerated. In order to illustrate such technological progress, Intel puts the Moore's law into the perspective of airline travel and notices that a commercial flight that costed \$900 and took seven hours in 1978, would cost about one penny and take less than one second in 2005. On the contrary, N. Carr, in 2003 [43], predicted that "the IT buildout is much closer to its end than its beginning" and insinuated that further adoption of IT would not lead to significant improvement of production.

Despite some pessimistic predictions such those of Carr, the strong improvement in computing performance, depicted by the Moore's law but also the wide enlargement of communication networks, the enhancement of the speed of data transmission as well as the increase of data storage capacity over several decades, led us to pay particular attention to the Information and Communication Technologies

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<sup>1</sup>See Kurzweil 2000 [143] and 2005 [144] for futurist scenarios



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(ICT henceforth). In particular, this leads us to wonder about the potential economic impact of ICT. We may ask whether these technologies belong to those that are fundamentally changing the production process and output and are able to support generalized productivity growth: the General Purpose Technologies.

The definition of General Purpose Technologies (GPT thereafter) introduced by Bresnahan and Trajtenberg (1995 [31]) is based on three characteristics summed up in Lipsey et al. (2006 [152]<sup>2</sup>):

1. Initially they present wide possibilities for development;
2. They could be used in various ways and they present possibilities for use in a lot of different sectors;
3. They offer large technological complementarities.

On one hand, their apparently dazzling technical progress suggests that ICT validates the first condition to be a GPT and, on the other hand, just look around, the computer is everywhere. Unless this is a smokescreen, we have thus strong reasons to believe that ICT is the contemporary dominant GPT.

In addition, the economic literature ( Van Ark et al, 2003 [229]; Gordon 2004, [94]) shows the important role ICT has in the increase of the productivity gap between U.S. and Europe and argues that this may be due to the lower ability of the latter to invent and use ICT. In other words, Europe seems to have not been able to exploit the full potential of the GPT features of ICT. Therefore, this also suggests that the benefits from a GPT are not spontaneous, but depend on the enabling feature of the environment.

As ICT innovation seems to be the starting point of the potential virtuous circle that we seek to study, we dedicate this first chapter to the analysis of the innovation activities in that field.

The aim of this chapter is threefold. The first objective is to depict the nature of the technical progress in ICT and note the sequence of great events in this field. The second objective is to use rational indicators of innovation in order to confirm that ICTs are really technologies that are subject of a rapid technical progress. We will find, in particular, some of these first indicators in the widest available sources of information on innovation, which are patent databases. In addition to the analysis of the technical progress, we aim to check whether patent data can highlight the other GPT properties of ICT, i.e. whether patent data can show both the pervasiveness and the technical complementarities

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<sup>2</sup>Actually, they identify four features but we group together two of them in the second feature of the list which underlies the ubiquity of the technology.

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of ICT. Finally, the last objective is to verify whether Europe is less innovative than the U.S. in the field of ICT or not and, in that case, bring some light on this situation.

One of the main originalities in this chapter is the way we use patent data. First, and this is not the originality, we use patent citation data instead of patent applications for two reasons. On one hand, granted patents do not have the same value in the sense that all patents do not represent the same level of innovation. And, according to the OECD patent statistics manual (2009 [239]): “the number of citations a patent receives has been found to reflect, on average, the technological and commercial importance of a patent, and thus helps to deal with the problem of the heterogeneity of patents’ value.” On the other hand, patent citations are useful in order to examine how ICT innovation induces or helps other innovations, “since these citations provide good evidence of the links between an innovation and its technological “antecedents” and “descendants”” (Trajtenberg, 1997 [219]). Secondly, the GPT conception established by Bresnahan and Trajtenberg (1995 [31]) and taken up by others, such as Lipsey et al. (2006 [152]), involves the notion of technology-innovating (or -producing) and technology-using industries. Indeed, the mechanism they describe relates to coordination problems between these two types of industries. In this respect, we must adopt a sectoral approach rather than a technological one. But unfortunately, the available data on patents do not allow us to use them in such an approach. Indeed, patents are referred according to the International Patent Classification (IPC) system, which categorises inventions by product or process instead of economic sectors. Thus, to be able to exploit the available data we turn them into sectoral data by the Johnson’s method (2002 [130]) that we will describe. In this chapter we study the characteristics of knowledge externalities involving ICT-producing and using industries through patent citations. For that purpose, the cited and citing patents are assigned either to the sector that produces them, that is to say the “invention producing” sectors, or to the sector that uses the invention, that is to say the “invention using” sectors. For instance, considering a patent on GPS equipment, the “invention producing” sector should be the ICT industry and the “invention using” sector should be the automobile industry.

In order to find evidence of GPT in ICT patent data, we will proceed in the manner of Hall and Trajtenberg (2004 [110]), using an indicator of generality (the index of Herfindahl) to test the pervasiveness and the technical complementarities with other sectors. We will also construct a weighted measure of this index, using correction to equilibrate sectors with respect to their weight in patent citations. In addition, we will test the relationship between the use of ICT based innovations and the rate of growth of innovation in each sector in order to point out evidence of the fact that ICT spurs

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innovation in downstream sectors.

This chapter is organized as follow. At first we proceed with a short historical review of the main ICT inventions, and the context in which the most important innovations were created, what they do and how they were harnessed to become a support for further innovations and for economic development. In this regard, we distinguish five determinant stages. The first stage highlights the fact that modern information and communication means are based on principles that were established over a very long period in a wide range of geographical areas. Next, the starting point of modern ICT is the mechanisation of information and the race for the leadership began with the digitisation of information. Then the three following stage that were determinant are: computer performance, user-friendliness and commucation networks.

In the second part, we carry out a descriptive analysis of current data that emphasizes the role of innovation in ICT industry. We especially highlight how important this industry has become globally in innovation activity and we make a comparative analysis between European countries, the U.S. and Japan.

Finally, in the third part, we examine knowledge externalities throught patent citation data. In particular we characterize countries' ICT innovation according to their ability to issue or receive knowledge externalities and, secondly, we check whether such data provide evidence of GPT features, especially to prove the pervasiveness of ICT industry innovations and their ability to accelerate innovation in downstream sectors. We will then show how patent data are suitable or not for such analysis.

### 2.2 A short story of ICT inventions

There exist an extent scientific literature and countless general public books on the history related to computer (Myers, 1998 [162] Singh, 1999 [209]; Cerruzi 2003 [44]; Campbell-Kelly and Asprey, 2004 [42] for instance) or to the Internet (e.g. Leiners et al., 1999 [148]; Berners Lee et al., 2000 [20]; Abbate, 2000 [1]; Mowery and Simcoe, 2002 [160]), and of ICT in general. The Web is also full of information about this topic. This survey does not attempt to go further in the ICT history than this existing literature but it aims to recall, on one hand, the nature of ICT inventions, highlighting that the technical progress took many forms, and, on the other hand, how and how far the United States took the lead in this field notably with respect to the European countries. We will review the different stages of the development of these technologies, each stage being characterized by a given field of innovation: theoretical basis, conception and improvement of machines, ergonomics or networks; the stages may overlap. In this way, we pointing out that taken ICT into account as GPT should be more complex than considering a single technology such as semiconductors in the sense that the development of ICT, defining GPT basic inventions, involve a lot of different types of innovation and technologies. At the same time, we will show that while the United States continuously provided most of ICT's major innovations in all stages during the 20th century, several European countries also made important contributions but were not able to benefit from their whole potential by creating an enabling environnement.

#### 2.2.1 The *pre-digital* era

Information and Communication Technologies (ICT), in its broad sense, designate a series of processes using a support that aims to transmit and format data. Therefore the ICT concept covers a very large field and the development of these techniques date back to very ancient times (prehistoric cave paintings may be included in such a definition). However, the contemporary acceptance of the expression refers particularly to computer and telecommunications and thus also implies the notions of rational processing and automatic machines as information support. But again, if the conceptualisation of these ICT is relatively recent, notably with the work of Shannon, Turing and Von Neumann, the basis is very old. Indeed, according to Schmandt-Besserat (1996 [197]), we find the oldest traces of rational processing data around 10 000 B.C. with the balls and token in southern Mesopotamia, around 6.5 thousand years before the advent of cuneiform script. The abacuses appeared in approximately 500

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AD in the Middle East.

Moreover, even in regard to the automation of data processing, the theoretical basics are not new. Indeed, many of the fundamental concepts used in the digital age were discovered before 1000 AD. We find the first use of the binary number system in the Ba gua trigrams, the magical symbol of the Chinese Emperor Fou-Hi based on Ying and Yang, 3000 BC. Five thousand years later, it intrigued Leibniz when he rediscovered binary arithmetic<sup>3</sup>. During the fourth century BC, Aristotle studied logic in his fundamental work *The Organon*. The advent of the algorithm appears in the works of Al Khwarizmi<sup>4</sup>, whose name is at the origin of the word. This work, disseminated in Europe by the arabic invasions, later led to the adoption of the arabic numeral system and the zero favoured by the Pope Sylvester II at the dawn of the second millenium. Another of the most important discoveries that allowed the development of modern computing and communication was made by the Scotsman John Napier (Neper) in 1614 and is the logarithm which reduces multiplications and divisions to additions and subtractions.

We are obviously not going to review in detail the history of rational data processing means but we wanted to recall some historical facts that underlie modern data processing and communication. In particular, we intended to recall that almost all basic principles of modern ICTs come from a slow process of innovation and discovery that began long time ago. Actually, the recent acceleration of technical progress concerns the development of automatic computing and communication systems and, thus, the ability to implement these principles rapidly.

Naturally, in this regard, we can also find old examples of mechanical automation of data processing such as the first clockworks and automatons, developped at the beginning of the second millenium, or the well known first calculatating machines like the Schickard's machine designed in 1623 or the Pascaline, invented in 1642 by B. Pascal, as well as the Leibniz's mechanical calculators. However, the 19th century announced the beginning of a turning point. It began with the Jacquard loom using punched cards<sup>5</sup> to control a sequence of operations which is therefore considered as a precursor of computer programming. Next, the works of the British Charles Babbage, who tried up until his death to built an analytical engine which had all the fondamental features of the modern computer and could have been the first "Turing-complete" machine, provided a significant technical advance, although

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<sup>3</sup>Which was considered at that time "more curious than usefull", dixit the encyclopedia of Diderot and D'Alembert

<sup>4</sup>The *Compendious Book on Calculation by Completion and Balancing* around 820 AD

<sup>5</sup>Based on the earlier invention of Falcon in 1728

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Babbage never managed to run its engine<sup>6</sup>. At the same time, Ada Lovelace, developing a program for the Babbage's engine, defined the principle of the loop and wrote the first encoded algorithm for processing by machine<sup>7</sup>. This century is also the one of "The Laws of Thought", published by G. Boole in 1854, that provides the mathematical foundations of logic that were used later in electronic systems by Shannon in 1938.

Important improvements were also made in communication technologies. Indeed, after the optical telegraph invented by the Chappe brothers, three noticeable inventions were realized in the United States: the electromagnetic relay by J. Henry leading to the electrical telegraph invented by S. Morse<sup>8</sup>(who invented also the Morse code) in 1938; the telephone which is invented by A.G. Bell in 1876 and the phonograph, invented by T. Edison in 1877<sup>9</sup>.

Lastly, the mechanical tabulator, developed by Hollerith (1884) after he won the government tender for the 1890 census, led to the development of the mechanical data processing<sup>10</sup>. But this technology was soon supplanted by others. The next step was the implementation of the binary system for data processing, that is to say the digitisation of information. We will focus on this new era by paying particular attention to the contexts in which innovations have been the most fruitful.

### 2.2.2 Computer and digitisation of information, the U.S. take the advantage

**The scholarly kitchen** We can find modern theoretical foundations in communications in C.E. Shannon's thesis in 1937 (published in 1940 [205] which established the link between boolean algebra and electrical systems using the binary digit) as well as in his post-war article, "A mathematical theory of communications" (1948 [206]). On the computing side, the Turing machine (1937 [223]) provided the definition of the computer concept and the notion of mechanical calculability. In addition, the report on the EDVAC<sup>11</sup> of von Neumann (1945 [233]) described the general principle of a data processing system.

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<sup>6</sup>Partly because the technology of the time was insufficient to produce parts accurately. Afterwards, his son will succeed in producing an operational prototype.

<sup>7</sup>Ada Lovelace is recognized as the first "computer programmer"

<sup>8</sup>The electrical relay and telegraph are also invented separately in United-Kingdom at the same time by E. Davy, W. Looke and C. Wheatstone in 1936-1937

<sup>9</sup>We can mention also the typewriter, invented in 1867 by Sholes and Glidden

<sup>10</sup>Concerning the Hollerith tabulator, the productivity gain was not so obvious, as the 1880 census, which was hand-made, took nine years and cost \$5.8 million while that of 1890, made using the tabulator, took 7 years but cost \$11.5 million. (M. Frauenfelder, 2007 [80])

<sup>11</sup>Electronic Discrete Variable Automatic Computer

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History attributes to G.R. Stibitz the primacy of the implementation of the binary system. This engineer working in the Bell Laboratories developed the model K<sup>12</sup> in 1937 which is the first digital calculating machine. With Williams, at the Bell Labs, he also developed the “Complex Number Calculator” that was able to make calculations in complex numbers as its name suggest. At about the same period (in 1938), on the other side of the Atlantic in Germany, K. Zuse, a statistician in an airline company, also worked on a machine based on the binary system, the “Versuchmodell 1” (or Z1), but unfortunately this was not exploited. In 1940, Stibitz and Williams took up another challenge and made the first demonstration of teleprocessing by sending commands to their *Complex Number Calculator* based in New York from a conference at Dartmouth College which is 400 km away. And three years later, in 1943, H. H. Aiken with IBM and Harvard constructed the Automatic Sequence Controlled Calculator (ASCC, also called the Harvard Mark I). The race to build computer began.

**Secret research VS. quasi-published research** On the European side, the World War II included another: the information war. In 1940, the British government established a big research center, Bletchley Park, in order to crack the *ENIGMA*<sup>13</sup> code as well as that of Lorentz machines, the German coding machines. During this period, this secret organisation, managed by A. Turing, led to great improvements in data processing and to the fundamentals of computer science with the conception of the *ROBINSON* and *COLOSSUS* machines. However, all the activities of this centre, as well as the fruits of its research, were classified top secret until 1975<sup>14</sup> and thus yielded neither civilian benefits nor externalities. Therefore, although, during the World War II, public investment in defense played a prominent part in research on data processing in United-Kingdom, unfortunately, it had no impact on private innovations or on the economic development in the sector.

Afterwards, the Cold War induced the American Army to increase its investments in these technologies. Nevertheless, the research strategy was very different and the social consequences certainly improved. Indeed, instead of the internalisation of research in the complete confidentiality, The Pentagon has contracted private firms such as Bell or IBM and made academic partnerships. So while the British secretly recruited using crossword contests in news papers and imposed silence on their recruits, the U.S. contracted with private firms that were afterwards authorized to benefit from these researches.

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<sup>12</sup>The letter K makes reference to the fact that the engineer developed it in his kitchen.

<sup>13</sup>*ENIGMA* was invented in 1919 by the Dutch H. Koch

<sup>14</sup>Following the publication of the Winterbotham’s book: *The Ultra Secret*

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Just before this period the concept of the digital computer was entering into use in U.S. with the development of the ENIAC<sup>15</sup> at the University of Pennsylvania by P. Eckert and J.W. Mauchly in 1946. The ENIAC is often recognized as the “first computer”<sup>16</sup> and was already on order from the U.S. army. Before the ENIAC was complete, Eckert and Mauchly also constructed the EDVAC<sup>17</sup> in collaboration with J. von Neumann and later (in 1951) they will also build the first commercial computer, the UNIVAC.

During the Cold War, the army’s demand was especially important in the field of telecommunication. In 1950, the U.S. army launched the SAGE (Semi-Automatic Ground Environment) project, which aimed to protect the North American territory against a potential Russian atomic attack. This automated control system has been established by IBM and was used until 1984. This system was also made possible by the construction of Whirlwind at the MIT which was the first computer that operated in real time.

Relying on its experience from the SABRE project, five years later, IBM developed the global distribution system (GDS) SABRE<sup>18</sup> for American Airlines, which represented the first big worldwide databank. This is a clear example of positive externality of the military investment as this would not have been possible if the army had built SAGE in a strictly confidential framework.

On the side of scientific research, this period is also marked by the discovery of the transistor in 1947 by Bardeen, Brattain and Shockley from Bell Labs. It was not until 1954 and the invention of the silicon transistor by Gordon that sufficiently low manufacturing costs were obtained permitting use in computers<sup>19</sup>: the TRADIC designed by Bell in 1955. From that moment, a second generation of computers appears, the transistor computer, with reduced costs and volumes. During the year 1958, another fundamental discovery is made by researchers from the Bell Company: the LASER. Nevertheless, it was not used in computer manufacturing until 1980.

In 1958, J. Kilby, from T.I., made a new technological leap towards miniaturization: he manufactured capacitors, resistors and transistors at the same time on a single plate of semiconductor materials, connecting them by threads welded to the plate: this is the first integrated circuit. The next year, R. Noyce (future founder of INTEL) developed a more effective technology. Added to the MOSFET

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<sup>15</sup>Electronic Numerical Integrator And Computer

<sup>16</sup>However, Eckert and Mauchly owe much to the works of Atanasoff and his student Berry who constructed the “ABC” (for Atanasoff Berry Computer), the first electronic digital computer, in 1940.

<sup>17</sup>based on ENIAC but uses binary instead of decimal

<sup>18</sup>Semi-Automatic Business-Research Environment

<sup>19</sup>However, the first application of the transistor appeared in hearing aids in 1952 (Sonotone Model 1010)



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(Metal Oxide Semiconductor Field Effect Transistor) technology, they will significantly reduce the size of computers as well as their cost again. We are now at the dawn of the minicomputer that up turned the computer industry.

So until that time, although the intervention of different agents, such as Government, University or private firms and individuals, led to many disagreements in the U.S.<sup>20</sup>, it also undoubtedly helped to generate and absorb many of externalities. This is certainly one of the reasons why the U.S. had a serious advantage during this pioneer period.

**The first implementations for professional applications: expert-systems and supercomputers** On the computer utilization side, the applications of computing machines, on one hand, fulfilled the increasing need for calculus that are impossible using classical methods, especially in nuclear physics research and, on other hand, were able to perform logical tasks and make decisions appropriate to the environment, which defines artificial intelligence (A.I.). The first implementation corresponding to the former aspect is linked to the conception of the first supercomputers, while the latter aspect lies in the first expert systems. The U.S. pioneered both sides and in a very eclectic way.

The first noticeable expert systems were developed for different application domains. In 1965, J. Weizenbaum at MIT developed the medical-expert system ELIZA, designed for psychoanalysis. At Stanford, E. Feigenbaum, in collaboration with the biologist J. Lederberg, built DRENDAL for the detection of chemical substances in 1968. T. Winograd, from the MIT, using logical syntax<sup>21</sup> and the programming language LISP that we shall see below, conceived, between 1968 and 1970, the SSHRDLU with the capacity to interact with the user with recognition of English terms. Among the early expert systems based on A.I. we can also mention MYCIN designed in the early 1970s at Stanford for the identification of bacteria causing infections, as well as HEARSAY capable of speech recognition, built in 1971 by R. Reddy and financed by the ARPA<sup>22</sup> project, or Arches by P.H. Winston for Architecture in 1973 and the Agricultural expert system AQII (1976) from the Illinois University.

The race for the supercomputer was also the preserve of the U.S. during this pioneer period in spite of several attempts by France, UK and the Soviet Union. Indeed, despite the existence of previous

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<sup>20</sup>We can in particular mention the two following lawsuits:

- IBM versus Harvard with the Mark I
- Eckert and Mauchly (University of Pennsylvania) versus Neumann (University of Princeton) about the EDVAC

<sup>21</sup>such as if/then

<sup>22</sup>Advance Research Projects Agency

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machines, such as the Gamma 60 from the French Bull Company built in 1958, or ATLAS I which was built in the United Kingdom by the University of Manchester and two firms, Ferranti and Plessey, and which was the first computer to introduce virtual memory and multiprogramming: the CDC (Control Data Corporation) 6600 designed by Semour Cray from Control Data marks the start, in 1964, of supercomputers with its 1 MFLOPS<sup>23</sup>. Moreover it was a great commercial success despite the false advertisement of the IBM 90, pretending to be the direct rival to the CDC 6600. In 1968, Control Data will uphold its leading position by the release of its new model, the CDC 7600. Meanwhile, in 1965, the Soviet Union, with S.A. Lebedev from ITMiVT, developed its own supercomputer, the BESM-6. But its performance did not equal that of the CDC. Afterwards, the Russians constructed in secrecy the M10 for the Russian Main Centre for Missile Attack Warning (called SPRN). The construction of this computer in 1973 was directed by M. Kartsev. Burrough conceived the ILLIAC IV for the NASA in 1972 that only became operational in 1975. However, despite its high performance, this computer faced strong implementation problems. Next, after leaving the Control Data Corporation, Semour Cray founded Cray Research Inc., conceived the CRAY I (in 1976) and Cray Research Inc. took over the market. In reaction Control Data produced the CYBER 203 in 1979 and the 205, the most powerful in its time with 200 MFLOPS, in 1981. So, one supercomputer followed another and so forth, with constantly improving performances and this situation continuous today. After the Cray X-MP (the first Cray multiprocessor computer), the firm releases the CRAY 2 in 1985 (10x Cray I, the first to go over 1 GFLOPS). In 1986, The firm Thinking Machine Corporation located in Massachussets commercialized the first computer with a massively parallel” arrangement of microprocessors.

Today, this is still an American company on the frontline, IBM with its IBM Sequoia (around 16 PFLOPS). Moreover, among the top 10 supercomputers in operation, 6 were produced by american company (5 by IBM and 1 by Cray and used in U.S., Germany and Spain), 2 by Chinese firms (and used in China), one by a Fujitsu in Japan (also used in Japan) and one by the French Bull (located at the CEA in France). We can add that, among the 10 last leaders, that is to say the 10 last that defined the frontline, 6 were American, 3 were Japanese and 1 Chines.

**The French failure** As Pierre-Eric Mounier-Kuhn pointed out in his book “L’informatique en France de la Seconde Guerre Mondial au Plan Calcul” (2010 [159]), France is the only industrialized country

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<sup>23</sup>Mega Floating point Operations Per Second, a unity for measuring computer’s performance. Another measure of computer’s speed is the number of Instructions Per Second (IPS). In comparaison ATLAS I achieved 200 KFLOPS

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where public research has failed to build a computer in the pioneer period. This author partly explains this failure by the lack of the national research during the inter-war period and especially in the electricity industry leading to low demand for calculation and computing machines. Next, the Occupation period made things worse. Nevertheless, the author wonders why France did not catch up in this area during Reconstruction whereas it succeeded in other sectors such as nuclear physics and aeronautic engineering. He argues that, first, the past leading position in nuclear physics and aeronautics motivated priority of research in these fields and, secondly, the weak academic recognition of computing, reflected notably by the orientation of research in mathematics to analysis rather than logic, closer to the computer, could provide an explanation of the weakness of research in computer science.

However the need for simulation in the leading sectors of aeronautic engineering and nuclear physics finally led to an increased demand for computing. Thus in the early 1960s, the State required computers for the nuclear program. French manufacturers of telecommunication equipment and mechanical data processing machines, such as CGE<sup>24</sup> (Alcatel), Thomson or Bull, engaged in the production of computers mainly under American license. But their conversion to computing could not rival American competition and especially the supremacy of IBM. Bull, although at the forefront of technology with its multi-task computer, the Gamma 60, was financially weakened by the acquisition of a subsidiary and was acquired by General Electric in 1964 and afterwards by Honeywell. That is when the French government was faced by the American refusal in 1963 to provide large computer systems, and high-tech equipment, under the pretext of an anti-proliferation policy. In this context, the French president De Gaulle, encouraged by Michel Debré and the Ortol Report, launched the first “Plan Calcul”<sup>25</sup> in 1966 designed to support a national computer industry and the independence of the French state vis-à-vis other countries in this field, which means the preservation of French “computer sovereignty”.

This plan created two major entities: a public research center in computer science, the IRIA (Insitut de Recherche en Informatique et en Automatique, which is became INRIA<sup>26</sup>), and a large computer company subsidized by the state, the CII (Companie Internationale d’Informatique), merging two competitor subsidiaries: the SEA (Société d’Electronique et d’Automatisme) at Schneider and the CAE (Companie européenne d’Automatisme Electronique), a holding company belonging to CGE, CSF (Compagnie Générale de Télégraphie Sans Fil) et Intertechnique. However this enterprise has never broke even. Shortly after this initiative, in 1972, a European consortium was also created:

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<sup>24</sup>Companie Générale d’Electricité

<sup>25</sup>Which will be extended by the second “Plan Calcul” in 1971.

<sup>26</sup>Insitut National de Recherche en Informatique et en Automatique

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Unidata, which aimed to promote the development of a European computer industry like Airbus in aeronautics. This consortium was constituted by the CII (responsible for machine architecture and softwares), Philips (responsible for electronics) and Siemens (for mechanical devices). Notwithstanding, in 1975, given the budget for the project and facing the oil shock, President Valéry Giscard d'Estain ended the project and the CII was taken over by Honeywell-Bull.

Despite these failures in the promotion of a competitive computing equipment industry, France later reached the technological frontier in terms of telecommunications with the Minitel. This was not without importance since, the transmission of the information and the development of wide cover networks constituted an essential part of ICT. But again, as we will see thereafter, the game was not won.

### 2.2.3 User-friendliness and popularization, the U.S. score a try

**Codes and programming standards** One of the first steps to user-friendliness, the ability to be widely and easily used, was the homogenisation of languages in programming and data transmission.

In the field of programming standards, the U.S. once again took the lead, but Europe was not far away. The story of the standardization makes its real departure at the end of the 50's and the early 1960s and continues to evolve until now. Here are some of the first key points in this field.

In 1954, John Backus published a preliminary report which led, two years later, to the first general-purpose imperative programming language, FORTRAN<sup>27</sup>, especially suited for scientific use. A few years later, in 1958, J. Mac Carthy<sup>28</sup> developed the first standard language for programming artificial intelligence at the MIT, which is called LISP<sup>29</sup>.

On the international level, following a conference in Zurich and a UNESCO project (IAL, International Algorithmic Language), Europe and the United States agreed on the need for a standard and universal language. Then, in 1958, ALGOL 58<sup>30</sup> was defined, inspired partly by LISP, and revised in 1960 by the Applied Mathematical Center of Amsterdam in partnership with Backus. Both Americans and Europeans approved this charter of algorithmic language. Nevertheless, it has not been adopted in America, because of the reluctance of IBM. Furthermore, at the same times, in the United States, an-

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<sup>27</sup>FORmula TRANslator

<sup>28</sup>He invented the term "Artificial Intelligence" and was the co-founder of Massachusetts Institute of Technology's AI laboratory with Marvin Lee Minsky in 1957

<sup>29</sup>For List Processing

<sup>30</sup>Further versions will be developed afterwards, given ALGOL 60 and ALGOL 68

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other standardization of programming was initiated by The Pentagon, which organized the “COnterference on DATA SYstem Languages (CODASYL)”<sup>31</sup>, based on pioneer G. Hopper’s works on FLOW-MATIC language. This led to the definition of COBOL (COmmon Business Oriented Language). This is the latter that dominated commercial uses during the following years, competing with the Algols, less suited to business, finance, and administrative domains.

In 1960, the Norewegian Computing Center developed the simulation programming language Simula. In 1964, two mathematical professors from Dartmouth College that would provide computer access to their non-specialist students, J. Kemeny and T. Kurtz, created the BASIC<sup>32</sup> language which, in addition, was destined for “timesharing”<sup>33</sup>. The use of this language underwent explosive growth after the introduction of the microcomputer in the mid 1970s. For the same educational purpose in 1968, the Swiss N. Wirth developed the PASCAL language to provide a programming tool that was less complex than ALGOL 68.

Alongside the development of the operating system (OS), UNIX created by the Bell Labs, D. Ritchie, from Bell Labs, in 1972 created the C language which enjoyed a great success. We can also mention the Frenchman A. Comerauer who developed PROLOG<sup>34</sup> in the same year.

In 1979, The Pentagon decided to define a specification to standardize the languages used by its various services and, following the work undertaken by the HOLWG<sup>35</sup>, in 1983, The Pentagon chose the language Ada, which was developed by the French J. Ichbiah from the company CII-Honeywell-Bull.

Since then, other programming languages have been created and, among them, we can mention some of the most important in terms of popularity. The table 2.1 shows the ranking of the top 10 popular programming languages according to the TIOBE Index. It highlights how the U.S. dominates the world of programming languages.

We will return to the protocol standards related to communications and the Internet later and we will now focus on hardware miniaturization and popularization.

**User-friendliness: miniaturization and ergonomics** The real attempt to improve ergonomics began with the American Gilmore (from the MIT) in 1956 who developed the first real human-machine

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<sup>31</sup>Exactly one year after the Zürich meeting

<sup>32</sup>Beginner’s All-purpose Symbolic Instruction Code

<sup>33</sup>It was built in order to program for the Dartmouth Time-Sharing System also designed by Kemeny and Kurtz. The time-sharing system was developed in the framework of the MAC (Multi-Access Computer) project directed by J. Mc Carthy at the MIT.

<sup>34</sup>PROgrammation en LOGique

<sup>35</sup>High Order Language Working Group

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Table 2.1: Top 10 languages according to the TIOBE Index, June 2012

Rank	Programming Language	Author/Firm	Country of Origin	Approximative Year of early version
1	C	D. Ritchie & K. Thompson/AT&T Bell Labs	USA	1972
2	Java	J. Gosling & P. Naughton/Sun Microsystems	USA	1995
3	C++	B. Stroustrup/AT&T Bell Labs	USA	1980
4	Objective-C	B. Cox/AT&T Bell Labs	USA	1980
5	C#	A. Hejlsberg/Microsoft	USA	2000
6	Visual Basic	A. Copper/Microsoft	USA	1991
7	PHP	Lerdorf	DK-CAN	1994
8	Python	Rossum/CWI-CNRI-BeOpen	NL-USA	1990
9	Perl	L. Wall	USA	1987
10	Ruby	Y. Matsumoto	JP	1993

Source: TIOBE Software, June 2012

Note: Ranking of the top 10 popular programming languages according to the TIOBE Index; The ratings are based on the number of skilled engineers world-wide, courses and third party vendors. The popular search engines Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings. Further details on the TIOBE Index definition can be find here: [http://www.tiobe.com/index.php/content/paperinfo/tpci/tpci\\_definition.htm](http://www.tiobe.com/index.php/content/paperinfo/tpci/tpci_definition.htm)

interface, on the TX.O., using an oscilloscope, a light pen, a Flexowriter and function keys. Next, in 1960, the Digital Equipment Corporation (DEC) produced its first computer, the PDP 1, based on the pioneered TX.O. The PDP-1 made a great leap in reducing dimension and price<sup>36</sup> Moreover, this computer is well-known as it was the first microcomputer in history used for playing a game: Spacewar.

Beyond the ergonomic aspect of the computer, its ability to evolve as well as varied compatible devices more than ever became important features given the costs of investment. For that purpose, IBM launched its IBM system/360 (in 1964), which is a mainframe computer family, that is to say an entire series of computers (or CPUs) from small to large, low to high performance, all using the same instruction set. The flexibility and the compatibility of this series lowered barriers to entry since it allowed customers to use a cheaper model and then upgrade to larger systems as their needs increased without the time and expense of rewriting software or changing peripherals.

In 1968, as a return to miniaturization, DEC commercializes its successful PDP 8 minicomputer which is considered as the first easy to use low cost minicomputer. At the same time, the addition of integrated circuits in computers (B2500 and 3500 from Buroughs) as well as the MOS<sup>37</sup> technology again improved the possibilities of miniaturization.

Then, in the early 70s, the computer enhanced its computing performance and its memory. In 1970,

<sup>36</sup>The PDP-1's price was about US\$120,000 that we can compared to the UNIVAC whose price was between \$1,250,000 and \$1,500,000 although it was originally priced at US\$159,000.

<sup>37</sup>Metal-Oxide Semiconductor

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INTEL replaced the ferrite toroid by the electronic chip<sup>38</sup> and over the next years it introduced the first commercialized micro-processor INTEL 4004<sup>39</sup> that heralded the arrival of microcomputer. The Japanese firm Busicom, which bought the rights to the conception of the chip from INTEL in 1969, first used this microprocessor in its desktop calculator-printer and conserved the exclusive rights until 1971. In 1973, the Large Scale Integration (LSI) permitted to increase the number of components per square centimeter from 1000 to 10000 and later the Very Large Scale Integration multiplied again the possibilities in the mid 80s by 10. Concerning the memory, in the early 1970s IBM commercialized the first Floppy Disk which is much less bulky than punch cards. It became widely used in PC to store and transfer data or programs.

In addition to miniaturization, during the end of the 60s and the over the 70s, we saw the emergence of user-friendliness with the arrival of elements that allowed considerable improvement. One place has play a prominent role in innovation in this field: the Palo Alto Research Center (the PARC) created in 1970 by Rank Xerox<sup>40</sup>. Indeed, in 1972 inside the PARC, A. Kay developed the SMALLTALK, an object-oriented<sup>41</sup> programming language that displays documents and graphics in windows and icons. The first publicly available version will be created in 1980. This inventor also created the first laptop (or tablet) computer with, in addition, a desktop environment, the Dynabook, but Xerox did not commercialize it. Furthermore, another of his inventions was not used by Xerox but launched Apple's success: the Alto, which, in 1975, was the first computer with a desktop environment including icon-sand a mouse previously, presented by D. Engelbart from the Stanford Research Institute (SRI). This computer allowed display of graphic images and could be connected to other computers in networks.

From now on, the basis of the user-friendliness being established, "the computer for everyone" project can begin...in U.S. again!

**The home computer comes out of the garage** In 1975, E Roberts, who founded MITS<sup>42</sup>, and F. Mims produced and sold (in kit form in Popular Electronics) the ALTAIR 8800 which was the first

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<sup>38</sup>A square of 0.5 x 0.5 mm can replace 1024 toroids that occupies 2 square meters.

<sup>39</sup>Its performance is comparable to the ENIAC which weighed 30 tons and occupied 167m<sup>2</sup> (<http://encyclopedia2.thefreedictionary.com/ENIAC>)

<sup>40</sup>It was originally an Anglo-American joint venture between the U.S. Xerox Corporation and the Rank Organisation of UK but, after a short time, Xerox held the majority interest.

<sup>41</sup>An Object-Oriented Programming (OOP) is a programming paradigm using "objects" – data structures consisting of data fields and methods together with their interactions – to design applications and computer programs. It was developed by Norwegian Ole-Johan Dahl and Kristen Nygaard in the early '60s and continued through the work of Alan Kay in the 1970s.

<sup>42</sup>Micro Instrumentation and Telemetry Systems, was founded in 1968 in New Mexico and sold electronic kits for model rocket hobbyists.

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mass produced microcomputer. This computer was a great commercial success and the previously debt-ridden firm rakes in US\$250,000 profits. In 1975, two young people, William Gates and Paul Allen proposed software for the ALTAIR, which basically only served to flash lights for model rocket hobbyists, to Roberts. They then created Microsoft and the OS ALTAIR BASIC was the first product of the famous firm<sup>43</sup>. However, MITS could not withstood the competition and the firm went bankrupt in 1997.

In the same time, in 1976, S. Wozniak designed the Apple I and in 1977, the firm Apple, founded also by two young people, S. Wozniak and S. Jobs, from their garage just like Microsoft, launched the Apple II that was a remarkable mass commercial success.

The competition is so fierce between Apple and IBM. Following the Apple II, the world number 1 launched the IBM-PC to recover its market share. Furthermore, to the same end, IBM allowed other hardware companies to produce computer “clones” running the same software. However, because these manufacturers will learn to circumvent the IBM license and make compatible machines instead of clones, this will serve Microsoft more than IBM. Other producers, mainly American, also shared the microcomputer market such as Xerox (with the Star 8010 that was technologically ahead but too expensive), Osborne (that produced the first laptop Osborn 1) and Sinclair. In UK, the BBC and Acorn made and sold a microcomputer too. It was then that Apple won the game with the MACINTOSH and LISA<sup>44</sup> that introduced a very userfriendly environment<sup>45</sup>.

In addition to the competition between microcomputer producers, competition also became intense between processor producers, especially between Intel that provided IBM-PC with its 8088 and Motorola that provided Apple with the processor 68000.

On the other hand, the late 70s and 80s were also the time of user-friendly software development with the first word processors such as Lexitron, VYDEC, Wang and the Wordstar as well as spreadsheet software such as VISICALC and software databases such as DBASE (or VULCAN by W. Ratliff from the NASA) or LOTUS developed by M. Kapor for the IBM-PC and 4D built by the French A. Ribardière that became the standard for MACINTOSH. In 1981 the first integrated software, Vision, which includes word processor, spreadsheet and database software, is created by VISICORP. This is a

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<sup>43</sup>The first OS for microprocessors was actually the CPM (Control Programm for Microcomputer) created by G. Kildall that founded Intergalactic Digital Research but its success was limited after it was taken back by Microsoft for a contract with IBM.

<sup>44</sup>LISA was deeply inspired by the Xerox computer Alto and, for that matter, Apple poached the Xerox research team that created the Alto

<sup>45</sup>with among other the Copy/Paste by moving icons



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commercial failure but many others followed suite (such as Framework or Works). We can also mention desktop publishing software (DPS) such as Postscript developed in 1982 by J. Warnock (founder of Adobe Systems) or Page Maker by Aldus for Apple and graphics painting software such as Mac Paint for the MACINTOSH.

Concerning the operating systems (OS), UNIX was created by the Bell Labs at AT&T and Berkley University. Bell was pushed (in 1975) by the antitrust law to give UNIX away for free to universities that, then, improved it continuously. It also favoured the GNU project which consists in a mass collaboration between computer buffs to develop an OS called GNU<sup>46</sup>. The commercial OS market is now dominated by two main OS, the first made by Microsoft (far ahead in the number of users) and the second by Apple. Microsoft developed its MS-DOS<sup>47</sup> in 1981 for IBM-PC and developed the grafical interface Windows in 1985 in order to compete with the MAC family from Apple.

**Peripheral electronic devices** Many device innovations revolve around information technology and contributed to the popularization of ICTs. Here are some of them. First, we can mention a famous invention that was created in 1974 by R. Moreno in France: the smart card. The Compact Disk, developed by the Dutch firm Philips and commercialized by it and the Japanese Sony Corp. in 1979, is also a notable invention. In particular, this had also direct link to computers with its enhancement as a CD-ROM<sup>48</sup> in 1984, an extension of the audio CD allowing data access by computer and afterwards it is writable by computer with the CD-R (Recordable) in 1990 and the CD-RW (ReWritable) in 1997. However, the use of this support seems reduced recently with the advent of the portable storage and player devices such as MP3 players (whose development was made possible partly with the discovery of the Giant MagnetoResistance Effect or GMR by the French and German researchers A. Fert and P. Grünberg). Today, smartphones and tablets as well as other Smart Personal Object Technology (SPOT) open up important new markets.

### 2.2.4 Telematics and the Internet, the U.S. convert the try

**The birth of modern telecommunications** One of the crucial starting points for modern communication technology is certainly the rediscovery of geostationary Earth Orbit by John Pierce in 1954.

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<sup>46</sup>Gnu is Not Unix

<sup>47</sup>Micro Soft Disc Operating System

<sup>48</sup>Compact Disk Read Only Memory

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This was previously identified by Clarke in 1945 but his works were hitherto remained unnoticed<sup>49</sup>, but now this orbit is also known as the Clark belt. In 1962, the first telecommunication satellite, Telstar, is launched and retransmits radio signals for the first time between the U.S. and Europe and, three years later, the US launched, with an extensive media coverage, the first geostationary satellite for international communications, EARLY-BIRD constructed by Hughes Aircraft (that belong to Boeing now). Afterwards, at the end of the 80s, satellite launches became common.

On the side of the efficiency of the communication process, we can mention two great inventions. First, between 1960 and 1962 the works of L. Kleinrock and then of P. Baran and D. Davies led to the invention of the packet-switching<sup>50</sup> that played also a prominent role in the evolution of networks and enabled the future Internet Protocol (IP). Next, in 1967, the Swede Olof Soderblom invented the Token Ring that will be widely used by IBM<sup>51</sup>. This protocol consists of replacing intersections with roundabouts and reduced congestion information flows and the efficiency of communication was greatly improved.

In 1965, the MAC project directed by J. Mc Carthy at the MIT led to one of the first implementations of electronic mailing between users. Later, with the increase of network connections, email were used between users from different systems and R. Tomlinson<sup>52</sup> made further developments that allowed its generalisation.

At this time in the United Kingdom, the theoretical works of Charles K. Kao and George Hockham in 1966 also brought very useful information for the future development of optical fiber.

Either in the interest of national defense or simply with the intention to increase communication between universities, in 1969, ARPA<sup>53</sup> in the United States launched the ARPANET<sup>54</sup> that was the world's first operational packet switching network and the core network of a set that came to compose the global Internet. This federal project inspired private firms that launched their own commercial telematics networks such as Telenet Communication Corporation and Tymnet. Nevertheless, the British Donald Davies developed a packet switching network at the National Physical Laboratory in UK (MARK I project) which inspired the builder of ARPANET and was operational until 1986. However, this network was conceived to run with British machines that was withdrawn from

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<sup>49</sup>John Pierce ignored the Clark's founding

<sup>50</sup>The message to send is broken and the packets are forwarded without predetermined connection.

<sup>51</sup>That will compensate Soderblom after a long lawsuit

<sup>52</sup>The man who is at the origin of the use of the @ in email addresses.

<sup>53</sup>Advanced Research Projects Agency

<sup>54</sup>Advanced Research Projects Agency Network

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the market and the NPL was constrained to use Honeywell and DEC machines (Abbate, 2000 [1]). Next in France, the CYCLADES network was also built in 1972 by Louis Pouzin<sup>55</sup>, connecting several databases located at different places of the French government. These other networks provided significant technical advances but, as depicted by Mowery and Simcoe (2002 [160]), they did not benefit from “sustained and substantial development funding and from large-scale deployment” as well as from organizational diversity involving University, firm, research institute and government like their competitor ARPANET.

In October 1972, the first conference on computer communication was organized in Washington during which a demonstration of ARPANET took place and where an international agreement has been prepared on the need to define a common communication protocol creating the INWG (International Network Working Group) directed by V. Cerf<sup>56</sup>. Following this conference, one year after, B. Kahn and V. Cerf, aiming to fill in deficiencies of the NCP, presented a paper defining the internet protocol TCP/IP<sup>57</sup>, which is still the rule now. This protocol, for the first time, allowed multiple networks to connect with each other together in 1977<sup>58</sup> and ARPANET will switch to this procole on 1<sup>st</sup> January, 1983.

In 1973, a first satellite link was set up for connecting the University of Hawaii on the network and, concerning the local networks, R. Metcalfe created the ETHERNET at XEROX that again played a major role in the development of such networks. The next year Telenet, the first commercial packet switching network, was launched by the company BBN<sup>59</sup>.

On the other hand, IBM in order to simplify networks that became too complex and inconsistent, proposed the SNA (System Network Architecture) to the International Telecommunication Union (ITU). However, in view of the size of IBM, the international telecommunication companies feared the hegemony of an IBM standard in this field and thus pressured the ITU to adopt the standard X25 in 1976.

In 1979, CompuServe, founded ten years previously, release the first commercial service for electronic mail and online support.

When, in 1980, V. Cerf, working for the DARPA<sup>60</sup>, proposed the interconnection between the two

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<sup>55</sup>It was financed by the INRIA

<sup>56</sup>Until that time, ARPANET was based on the NCP (Network Control Protocol) established by the Network Working Group (NWG) in 1970.

<sup>57</sup>Transmission Control Protocol / Internet Protocol

<sup>58</sup>The three connected networks were ARPANET, Packet Radio Net and SATNET

<sup>59</sup>Bolt, Beranek and Newman

<sup>60</sup>The new name of the ARPA, adding D for Defense

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networks CSNET and ARPANET using the TCP/IP protocol, Internet was launched. Especially as on the other hand, ARPANET split into two parts: the Military Network (MILNET<sup>61</sup>) and the civil university network (the NSFNet<sup>62</sup>). The extension of the networks and the increase in number of users required further innovations such as the DNS (Domain Name Server) introduced in 1984, in order to be able to “find” a computer on Internet. It was also accompanied by the creation and the development of business enterprises such as Cisco Systems that was founded<sup>63</sup> by S. Lerner and L. Bosack from San Francisco and produced the first routeurs allowing interconnexions between networks using different protocols (the internet backbone). The first commercial Internet service providers appeared in U.S. in 1989 and Internet providers as well as online services took off (with the three largest: Prodigy, CompuServe or American Online), becoming extremely profitable after 1995.

From that time, connexions have increased exponentially. In August 1981, 213 machines were connected to the Internet, in 1987 we reached ten thousand connected computers, the 100,000 was reached in 1989, the million in 1992. In 2010, according to IMS Research Institute, we have surpassed 5 billion connected objects and this same institute predicts 20 billion in 2020.

**In France an alternative path was taken** In 1979, TRANSPAC, the first French packet switching network was launched by the DGT<sup>64</sup> and France Télécom<sup>65</sup>. Actually, this initiative resulted from a previous reflexion.

In 1977, a famous report entitled the Computerization of the Society and also known as the Nora-Minc Report (S. Nora and A. Minc published in 1978 [165]<sup>66</sup>) which defined the “telematics”<sup>67</sup>, launched a new technological enterprise supervised by the government: the launch, between 1980 and 1981, of a videotex network, the Télétel, connected to low cost terminals, the Minitel<sup>68</sup>.

This deployment of telematics network infrastructure, enabled France to take a considerable lead in terms of ICT use by making available among others banking information, e-commerce, messaging and forums. The first implementation of the Minitel services was the electronic directory. Although it

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<sup>61</sup>that will become after Data Defense Network, DDN

<sup>62</sup>National Science Foundation Network

<sup>63</sup>in 1984

<sup>64</sup>Direction Général des Télécommunications

<sup>65</sup>This network adopts the X25 standard

<sup>66</sup>The estimate number of copies in 1989 is about 125 000 (A. Walliser, 1989 [234]). The english version is published by MIT Press, 1980 [166]

<sup>67</sup>Which consists in any integrated use of telecommunications and computers that we now call ICT

<sup>68</sup>At the time of this writing, the Minitel lives his last days as France Telecom finally closes the service as well as the X25 protocol and the TRANSPAC network on June 30, 2012

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was supplanted by the Internet, the Minitel had two opposing effects on the switch to Internet<sup>69</sup>:

- The first one is negative and relates to the cost of obsolescence of the Teletel infrastructures and is also due to the cost free of terminals unlike then expensive computers needed to access the Internet.
- The second one is positive and relates to the early use of such technology and the accumulation of knowledge in terms of utilization.

Finally, it seems that this apparent failure was salutary as the experience accumulated in its utilization was quite valuable for Internet adoption, given the similarity of the services offered in both cases.

**The crowning achievement of the communication networks: the WWW.** In the late 80s, the British engineer T. Berners-Lee, working at the CERN, made a fundamental innovation<sup>70</sup> that broadened the possibilities of the Internet utilization. This is a system of interlinked hypertext documents accessed via the Internet: the World Wide Web<sup>71</sup>. This invention, which was only used by the CERN at the beginning, was put into the public domain in 1993. In addition to the Internet, the use of the WWW needs a program that we call browser. The browser that launched in 1993 the WWW was the free one written by Marc Andreessen at the National Center for Supercomputing Applications (NCSA) in the University of Illinois, Mosaic<sup>72</sup>. The W3C (World Wide Web Consortium) was then created the next year. Its use was exponential and a host of innovative internet applications was based on it.

Among them, in 1996, two students from Stanford, L. Page and S. Brin, developed a search engine which is becoming the most widely used dethroning the others such as Altavista, Lycos and Yahoo. This engine is called Google. Through the combination of the packet switching, the Internet, the World Wide Web, browsers and such search engines, access to information is changing radically.

In addition to the explosion of the information access, a multitude of new services appeared on the web. Some of the most important are the online selling sites such as eBay, PriceMinister, Amazon etc.,

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<sup>69</sup>The first French commercial Internet service providers emerge in 1993, four years after the U.S.

<sup>70</sup>The Belgian Robert Cailliau is also often associated to this invention

<sup>71</sup>It actually includes three main inventions:

- HTTP : HyperText Transfer Protocol which is the application protocol for client/server communications;
- HTML : Hypertext Markup Language which is a markup language;
- URL : Uniform Resource Locator defining the web address.

<sup>72</sup>Later, Netscape, the commercial browser version of Mosaic, embarked in a “browser war” with Microsoft and its Internet Explorer, see Cusumano and Yoffie (1998, [62])

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or online services allowing payments and money transfers such as PayPal. Since 2003, the professional and social networks, like Plaxo, Orkut, LinkedIn, Facebook, Twitter are also booming. In some cases, the new services offered on the net, like online music, still seem to have trouble finding their business model and even disturb the current one. For instance, Napster, an online system of exchanging music, revealed this problem in 1999 for the music industry that will probably need to revise its business model completely. In particular, two economic models seem to become more and more extensive. The first is based on service subscription, where the user pays a fixed amount for unlimited consumption of the service during a given period (fixed rate for unlimited listening online music during a month for instance). The second is based on compensation by advertising where the service producer is not paid by the consumption of the final service which is free but by the announcers and then the rental of advertising space in a parallel service<sup>73</sup>.

Obviously collateral damage appears, viruses and hacking are the main ones. In 1988, R. Morris disseminated the first computer worm on the internet. This same year, the famous hacker K. Mitnick was arrested (for the fifth time).

From now on, one of the aims of Internet is to dissociate information completely from its physical geographic location. One of the ways to reach this objective is cloud computing where computing resources are not stored in personal machines but on centralized servers providing access to user's data as well as to other resources such as software anywhere and from any machine<sup>74</sup>.

**The reasons for the success of the Internet** The historical analysis show that the US Internet absorbed or supplanted the other networks. The main reasons behind the success of the Internet may reside in two broad categories. The first category of reasons is inherent to the US specificities and to its historical context whereas the second category of reasons relies on the real technology's superiorities.

- *Country specificities and historical context:* At first, in the context of the Cold War, the development of the Internet benefited from the large investments of the American Department of Defense in order to protect the United States from a potential nuclear attack. Later, during the last stage of the Cold War that occurred when the network infrastructure was sufficient to enable the private firms to compete without prohibitive initial cost of development, the United States

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<sup>73</sup>We will return to this point in the next chapter

<sup>74</sup>The centralization of data in computer clusters may seem ironic beside the comparison of the computer with the dynamo made by David. Indeed, according to him, the dynamo's revolution lay in the unit drive system replacing the centralized steam power with the system of shafting and belt. So the Internet revolution may lie in the reverse process.

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made a judicious opening to private interconnexions<sup>75</sup>. Furthermore, the opening to private investment was also favoured by the antitrust and regulatory policies that weakened the market power of incumbent telecommunications monopolists<sup>76</sup> and enabled the arrival and the development of private domestic internet service provider (ISP) firms. In addition to this enabling political governance, the Internet certainly benefited from the large monoglot U.S. market.

- *Technology specificities*: The architecture and the technologies adopted by the Internet present a number of advantages with respect to other networks. In particular, the Internet demonstrated a great flexibility as well as a great robustness. These properties arise from several characteristics of this network. The first is that the Internet is a network of networks and that the TCP/IP ran on a large variety of network hardware and is an open standard. This leading to the large scalability of the Internet which, therefore, can be defined as a “universal network”. Moreover, the fact that the architecture is a distributed networking provides the Internet with a great robustness. The evolution of the network also benefited from a decentralized governance with informal organizations that made architectural and standards definitions (made by users) in contrast to some other networks such as the Minitel that used a proprietary architecture limiting the attractiveness for developpers and thus the development of applications and the scale of the network. The weakness of Intellectual Property Right in this field and the libertarian culture accentuate this aspect.

### 2.2.5 Conclusion

Through this short (and largely incomplete) browsing over modern information and communication technology, we tried to show how the United States took the lead in this field. In particular, we distinguished the technological fields and features, such as hardware, software, ergonomics or networks, that have enabled the wide diffusion of the ICT. We then saw that in each of these fields, the United States were one of the main driving forces behind development and most crucial innovations. Futhermore their technological predominance at the early stages of each information technology that benefited from network externalities, allowed U.S. to impose their standards and, their early and long investments

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<sup>75</sup>Resulting, in 1998, in the transfer of the governance of the development of the Internet from the NSF to the U.S. Department of Commerce.

<sup>76</sup>The antitrust policies were visible in the intervention of the Federal Communications Commission (FCC), the 1956 consent decrees against AT&T and IBM as well as, later, in the Telecommunication Act of 1996.

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in infrastructures allowed them to rapidly absorb and exploit foreign inventions, such as the WWW.

Factors for the success of the United States may be summed up in the following points:

- Close links between government, universities and firms;
- High and sustained investments in R&D and infrastructures;
- The military-civilian transfer;
- An early antitrust lawsuit;
- The abundant supply of Venture Capital.



### 2.3 Is ICT industry a very innovative sector?

In this next sections, we focus on the current situation and in particular we are interested by three questions:

- On what level is the ICT industry an intensive research and innovative sector?
- How data on R&D and patents underline the U.S. leadership?
- Does patent data provide any evidence of ICT as GPT?

We just reviewed some of the main remarkable innovations related to information and communication technologies. Besides the scientific and entrepreneurial adventures associated with these technologies, the speed of technical progress in this area in recent decades is impressive too. Thus, in this section we try to identify indicators that highlight the breadth of innovation in this field. In particular, we shall see that, looking at the intensity of R&D in ICT industries, innovation indeed plays a major role. On the other hand by observing of patent data, we will see also that the output of research in this field becomes less visible, wich looks like a decrease in innovation.

In a first part, we focus on the prominence of the importance of ICT industries in research and innovation. We also proceed with a short comparative analysis between countries, and especially between European countries, the United States and Japan. In a second part, we focus on patent data to assess the research output and we try to determine whether innovation in this sector is really slowing down or not.

#### 2.3.1 Production and research activity in ICT

A first economic indicator of the importance of technical progress in the field of ICT may reside in the R&D statistics. Indeed a high level of R&D expenditure reflects a high return in research activity due to either a high marginal benefit of invention or a high research productivity (i.e. either the importance of each technological leap or the number of inventions per unit of research engaged). In both cases this means that the R&D engaged in this field must have the capacity to increase the wealth of the innovator.

In order to assess the weight of ICT industries in the innovative activities, it is necessary to clearly define the framework of ICT sectors. As we shall see in more detail in the next chapter (see table 3.1 on page 102), under the name of ICT industries, we group *“manufacturing or services industries that*

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are intended to fulfil the function of information processing and communication - including storage, transmission and display - by electronic means"<sup>77</sup>. These industries mainly include the *Manufacturing of office accounting and computing machinery*, *ICT electrical goods* (which include radio, television and communication equipment), *Computer and related activities* (the industry of software publishing, data processing and information system consulting) and *Telecommunication services* (including access to electronic communication, internet and fixed or mobile telephony) plus the distribution sector of ICT goods.

Now, the weight of innovative activity that is ICT-oriented could be evaluated by the weight of R&D expenditure realized in the ICT sectors with respect to the total R&D, and, according to the OECD Stan Database, the ICT sector is indeed by far the largest R&D investing sector in the economy in US, EU and Japan.

Indeed, as we can see on the figure 2.2, ICT R&D represents between 15% and 30% of total private R&D for only 3.5% to 6% of the private value added (VA) (see figure 2.1)<sup>78</sup>.

These figures also show that the weight of the digital economy is higher in US and Japan in terms of both production and innovation activity than in almost all the European countries that are taken into account here<sup>79</sup>. Indeed only the United-Kingdom has a greater share of value added allocated to ICT production activity. In addition, even if we could moderate the comparison in terms of value added, since, excluding the post and telecommunication services industry, United-Kingdom, France, Germany and even Italy compete with the United States, the analysis of the share of R&D attributed to ICT remains unquestionable.

Focusing separately on the different ICT sectors, figures 2.3 show that ICT industries are highly R&D intensive in manufacturing industries, reaching 30% to 50% in Japan in *Office machine* sector as well as in USA and in Belgium and France in *Radio, television and communication equipment* industry in 2007.

In addition, the ranking of (European) countries depends strongly on the ICT sub-sector. The relative weight of the value added of the *Office accounting and computing machinery* industry in Germany (0.20%) and in UK (0.23%) is comparable to those in US (0.20%) and in Japan (0.28%), but the research intensity of the former is lower so that only Germany shows a significant higher share of

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<sup>77</sup>OECD, 2009 [170]

<sup>78</sup>The graph 2.1 includes Post services that should not be included in ICT industry, thus it provides an upwardly biased estimation of the weight of ICT industries in value added.

<sup>79</sup>We do not take into account the Netherlands despite of its important ICT activity because of some problems of data consistency.

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R&D in ICT (around 1.6%) than the other European countries. Concerning the *Manufacturing of ICT electrical equipment*, Germany and Austria with respectively 0.69% and 0.61% of their VA coming from this sector, are similar to the US (0.68%) but they are still far from Japan (2.11%) in terms of this sector's weight in the economy. Nevertheless, except in Italy, Portugal and Spain, research intensities in European countries are relatively similar to those of US and Japan, between 20% and 33%, and even superior in France with an R&D intensity of almost 50%.

Finally, in *Computer and related activities*, the United-States are by far the most R&D intensive country with more than 15% of the VA of the sector allocated to research investment. Among our studied European countries, Austria has the greater R&D intensity in this sector (around 8%) and it is followed by Spain, Portugal, Germany and Belgium with around 5% of the VA spent on R&D.

Therefore, globally these figures highlight that the US and Japan invest relatively more in ICT R&D than most European countries, but not systematically. Consequently, it is above all the combination of the weight of the sector's production and the importance of the intensity of R&D that leads to the high concentration of R&D in the ICT industry. In particular, the United States and Japan invest relatively more in R&D in sectors that are relatively more important than in European countries. Furthermore, the US and Japanese production systems are more specialized in the ICT manufacturing industry than European countries are. Finally, the United States invest a lot in research in ICT related services in addition to enjoyin a healthy innovative activity in the ICT manufacturing industries.

**Some further micro observations** Looking at individual firms, we can identify other features of the superiority of the U.S. with respect to Europe. Table 2.2 reports, for eight ICT industries, the ten firms that invested the most heavily in R&D in 2010.

So, first, we can see that, among these 80 companies, 42 are American, whereas only 14 are European (22 are in Asia, including 11 in Japan alone, and only 2 in the rest of the world). Moreover, the United States are present in all sectors, whereas European countries are missing in the Electronic equipment<sup>80</sup> industries as well as in Internet related services.

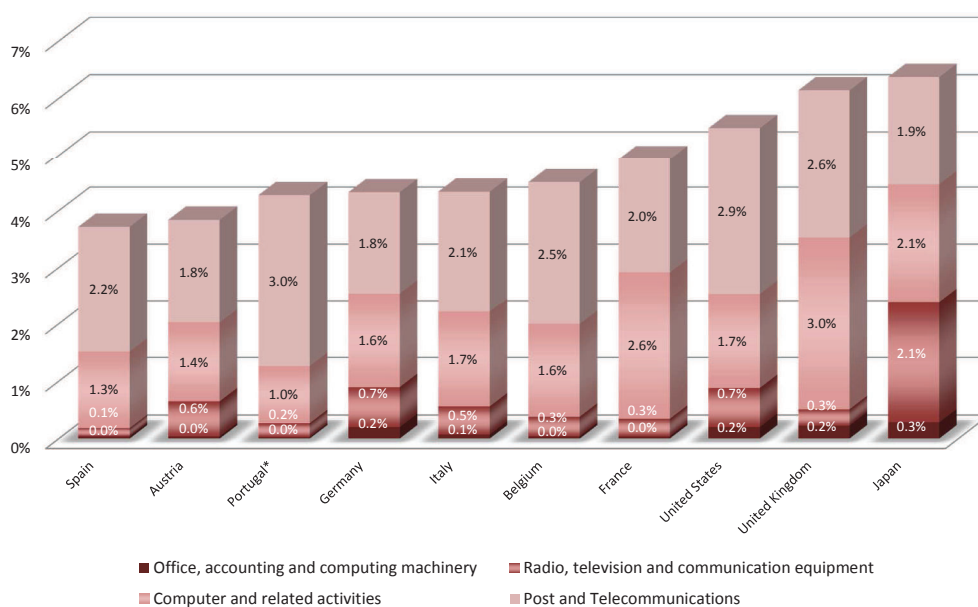
Another noticeable fact appears in this table: in the United States, most of the firms that invest a lot in ICT-R&D are highly concentrated in California, especially in sectors that are the most computer-hardware and Internet related (in these sectors 21 of the 36 US firms are in California). Whereas on the contrary, in Europe, firms are geographically more scattered. Moreover, Europe seems to demonstrate

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<sup>80</sup>We group together the sectors Electronic Equipment (2737) and Electronic Office Equipment (9574)

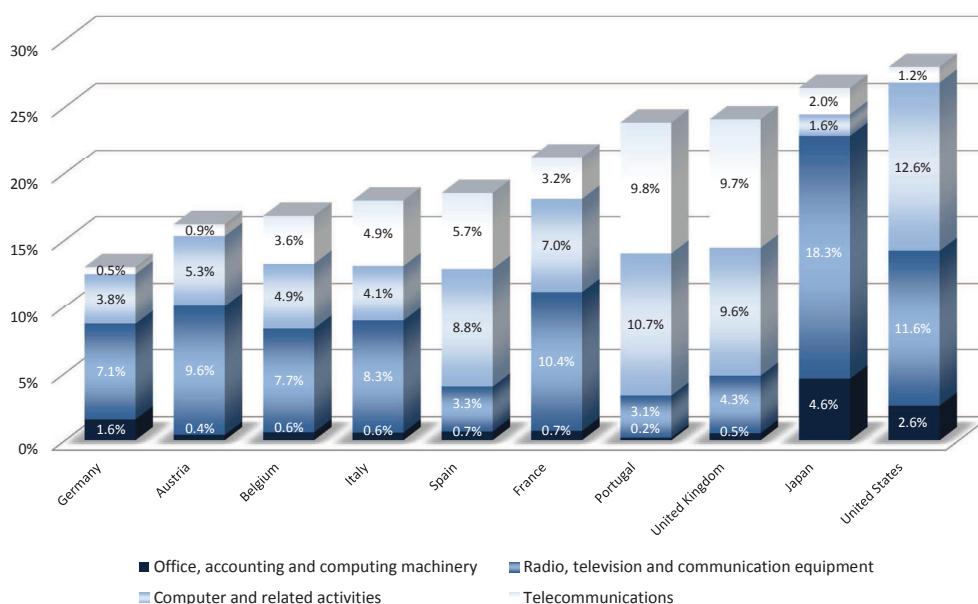
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Figure 2.1: Shares of ICT sectors in total VA of private sector in 2007



Source: OECD, STAN Database  
\*For Portugal the ratio is given for 2006

Figure 2.2: Shares of ICT R&D in total R&D business expenditures in 2007

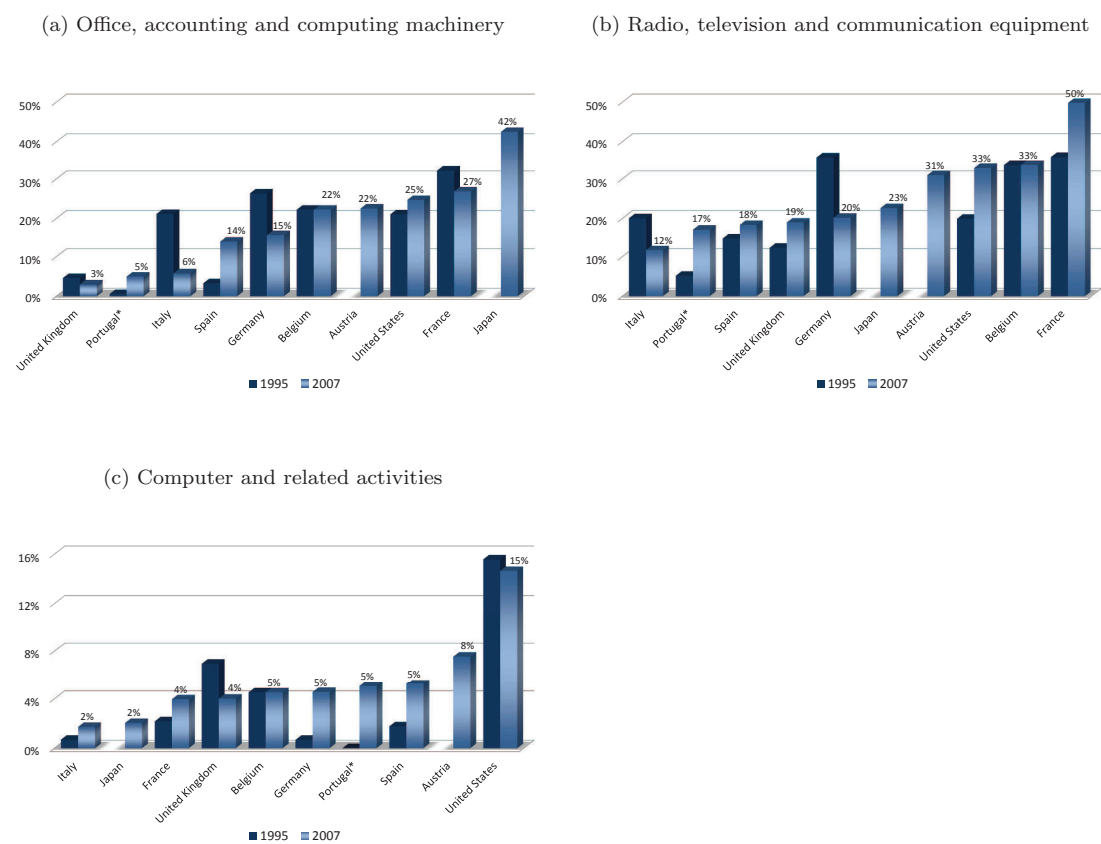


Source: OECD, ANBERD Database

Note: For all countries the disaggregation of the R&D is based on firms' main activities except for France and UK which is based on product field.

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Figure 2.3: R&D intensity in ICT industries, in percentage of value added



Source: OECD STAN Database

a real country-specificity in ICT industries, with firms belonging to the hardware and equipment goods industries in northern countries such as Ireland, the Netherlands, Finland and Sweden, and the presence of innovative firms in software and services in the western European countries such as Germany, France, United Kingdom, Italy and Spain. Only France appears also in second sector that are Telecommunications equipment with Alcatel-Lucent. In addition, all European countries are present in two sectors at most, except France which is present in software, telecommunication equipment and telecommunication services. Thus, not only each country has its sectoral specialization but every country seem to be limited to one or two sectors. Nevertheless, the R&D intensities of the European firms are close to the average R&D intensity of the 10 top R&D firms in all sectors in which they are present.

Finally, the US companies are far ahead in terms of number of biggest R&D firms in computer hardware, semiconductors and software. On the other hand, Japan's firms are particularly present in electronic equipment.

### 2.3.2 Measuring innovation in the ICT industry

**Patent citations as an indicator of research output** The levels of the research effort provide us with good information about the potential returns of the resulting innovations, but these data do not consist in a real measure of innovation. For that purpose, patent statistics, which are largely available, could give us some complementary information<sup>81</sup>. A patent could be considered as an output of research as it follows an invention. Nevertheless, patent data must be taken with cautiousness to measure innovation for many reasons:

Firstly, they do not cover all types of innovation. In particular, service innovations are often not patentable; the patentability of software, for instance, is heterogenous or at least unclear throughout the world<sup>82</sup>.

Secondly, the real value of each patent is very different with their mean values depending on both countries and sectors (OECD, 2009 [239]; Harhoff et al., 2002 [116]).

This heterogeneity has many sources. (i) On one hand, as depicted in appendix 2.6.1, it could come from the office-country bias, especially because of the differences (and changes) in standards and procedures. For instance, in Japan, the unity of an invention covers a smaller area than in other

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<sup>81</sup>see Griliches (1990 [101]) for a description about the use of patents as economic indicators.

<sup>82</sup>cf appendix 2.6.1

Table 2.2: World top 10 R&D companies in eight ICT industries

Computer hardware			Semiconductors			Electronic equipment				
Region	State/Country	Company	R&D	RD/NS*	Region	State/Country	Company	R&D	RD/NS*	
Asia	Japan	Hitachi	3423	4.2	USA	California	Intel	4902	15.1	
USA	California	Hewlett-Packard	2206	2.4	EU	The Netherlands	STMicroelectronics	1628	21.1	
USA	Massachusetts	EMC	1705	13.4	USA	California	Broadcom	1314	25.8	
USA	USA	Apple	1328	2.7	USA	Texas	Texas Instruments	1170	11.2	
EU	Ireland	Seagate Technology	654	7.7	USA	California	AMD	1047	21.6	
USA	Texas	Dell	493	1.1	USA	California	Applied Materials	852	12.0	
USA	California	NetApp	483	12.7	Asia	Taiwan	TSMC	760	7.1	
USA	California	Western Digital	455	6.2	USA	California <sup>(1)</sup>	Marvell Technology	669	24.9	
USA	Kentucky	Lexmark	275	8.8	USA	California	NVIDIA	633	24.0	
Asia	Taiwan	Wistron	253	1.6	Asia	Taiwan	MediaTek	596	20.5	
Average:			6.1	Average:			18.3	Average:		
Software			Computer services			Mobile & fixed line telecommunications				
Region	State/Country	Company	R&D	RD/NS*	Region	State/Country	Company	R&D	RD/NS*	
USA	Washington	Microsoft	6741	12.9	USA	New York	IBM	3788	5.1	
USA	California	Oracle	3369	12.7	Asia	Japan	NEC	2536	7.7	
EU	Germany	SAP	1730	13.9	Asia	Japan	Fujitsu	2068	4.8	
USA	California	Symantec	643	13.9	EU	Spain	Amadeus	326	12.0	
USA	California	Adobe Systems	507	17.9	USA	Pennsylvania	SunGard Data Systems	287	7.4	
USA	New York	CA	478	14.5	Asia	India	Prithvi	193	60.5	
USA	California	Intuit	469	18.0	EU	Spain	Indra Sistemas	184	7.2	
USA	California	Autodesk	370	25.4	USA	Ohio	Terradata	146	10.1	
USA	California	Synopsys	337	32.7	USA	Missouri	DST Systems	121	7.0	
EU	France	UBISoft	323	31.1	Asia	India	Appt. Cummins	110	64.5	
Average:			19.3	Average:			18.6	Average:		
Telecommunications equipment			Internet			Mobile & fixed line telecommunications				
Region	State/Country	Company	R&D	RD/NS*	Region	State/Country	Company	R&D	RD/NS*	
EU	Finland	Nokia	4938	11.6	USA	California	Google	2804	12.8	
USA	California	Cisco Systems	3931	13.2	USA	California	Yahoo!	889	18.8	
EU	Sweden	Ericsson	3022	13.4	Asia	China <sup>(2)</sup>	Tencent	191	8.6	
EU	France	Alcatel-Lucent	2559	16.2	Asia	China <sup>(2)</sup>	Baidu	81	9.1	
USA	California	Qualcomm	1900	23.2	USA	China <sup>(2)</sup>	Alibaba.com	66	10.4	
USA	Illinois	Motorola	1886	11.1	USA	Massachusetts	Akamai Technologies	65	8.6	
Asia	China	Huawei Technologies	1806	8.6	Asia	China	Sohu.com	56	12.3	
USA	Canada	Research In Motion	1007	6.8	USA	Minnesota	Digital River	49	18.0	
Asia	China	ZTE	897	11.3	USA	New York	IAC/InterActiveCorp	49	3.9	
USA	California	Juniper Networks	684	22.4	USA	California	United Online	48	7.0	
Average:			13.8	Average:			11.0	Average:		

Sources: Scoreboard, 2011

Note: R&D investment in 2010 in million current Euros

\*R&D/Net Sales in %

<sup>(1)</sup>Corporate Headquarters in Bermuda; <sup>(2)</sup>Incorporated in the Cayman Islands

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countries so that a same “invention”, which would be covered by a single patent in Europe, could result in five patents in Japan. In this way, the corresponding patent in Japan must be considered at a value five times lower than the European one. (ii) On the other hand, a second bias may occur between sectors since patenting strategies are different depending on the sector. For instance, in highly competitive sectors, firms could be encouraged to adopt an aggressive strategy for patent applications. In that case, they seek to file a maximum number of patents around a single idea in order to keep other companies occupying the same market. The mean value of patents is certainly lower in sectors where such a strategy is common. Similarly, a defensive strategy for patent applications, which is characterized by patenting technologies that the firm does not plan necessarily to use, can also be adopted. They may be due to the importance of cross-licensing arrangements that are often needed in manufacturing high-tech products. Here are two examples of the reasons for such strategy: (1) The company wants to prevent other companies from using the technology and thus files a patent application to keep it out of competitors’ hands. (2) The firm wants to hold a maximum number of patents around a given technology for potential cross-licensing arrangements or litigation. For instance, STMicroelectronics and Intel compete in a “patent portfolio race”. As it is almost impossible to do a perfect patent watch in view of the number of patents filed in their field, they make cross-licensing agreements based on the weight of each enterprise in total patents in that field<sup>83</sup>. Therefore each agent is encouraged to increase the number of patents it holds.

Moreover, these patenting biases play a non negligible role in ICT industries. Hall and Ziedonis (2001 [111]) showed that “one reason for rapid growth in semiconductor patenting after the mid-1980s is a conscious decision on the part of some major firms to build up their patent portfolios in order to fend off litigation and negotiate cross-licensing agreements.” In Exploring the patent explosion (2005 [107]), B. Hall also argues that “although R&D has also increased in this sector, this cannot explain the size of the increase in patenting” during the 1980s.

Therefore, the number of granted patents is not sufficient data for measuring innovation; plus the increase in patents granted does not necessarily reflect a real increase in innovation. In this matter, the economic literature on the measurement of the value of patents determines the value of any patent using the following additional data (see Guellec and Van Pottelsberghe, 2000 [106]):

- the number of times the patent is cited;

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<sup>83</sup>The agreement establishes a sort of probability for each agent to use (voluntarily or involuntarily) a technology patented by the other agent.



## CHAPTER 2. INNOVATION IN ICT INDUSTRIES

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- the length of its renewal;
- or the number of countries where it is taken out.

As Harhoff et al. (2002 [116]) suggest that the number of references to the patent literature as well as the citations a patent receives are positively related to its value, we will use here the first indicator of innovation based on patent citations. The OECD patent statistics manual (2009 [239]) explains why the real value of innovation may be approximated using patent citations:

“As citations indicate the S&T precedents in inventions, they make it possible to track knowledge. It is possible to identify the influence of particular inventions or particular sets of inventions and map their diffusion through the economy. In particular, the number of citations a patent receives has been found to reflect, on average, the technological and commercial importance of a patent, and thus helps to deal with the problem of the heterogeneity of patents’ value.”

Therefore, a measure that combines both the number of granted patents and the number of citations received per patent could give a more reliable indication of innovation than the number of patents granted alone. We thus take, as an indicator of innovation in ICT industries, the number of citations received by all patents filed in these sectors<sup>84</sup>. For that purpose, we use a patent citations matrix that was constructed by H. Meijers and B. Verspagen in the framework of the European DEMETER project. We will come back to the definition and the construction of this matrix in the next section and we will describe it in more detail in appendix 2.6.2.

From this matrix, we obtain the following first results:

Figure 2.4 show the shares of citations received by patents that belong to ICT manufacturing industries in total patent citations in thirteen countries. It shows that the ICT sector counts for 20% to 60% of patent citations according to the country (and even up to 70% in Finland), even if the home bias citation<sup>85</sup> is eliminated (Fig. b). This highlights a high productivity in research in this industry in terms of patenting applications or patent value. Nevertheless, these results must be

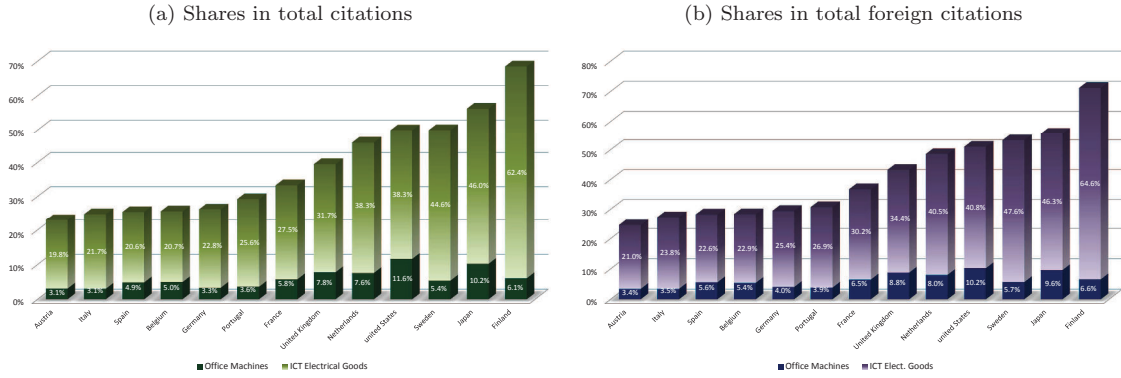
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<sup>84</sup>This indicator corresponds to the multiplication *Number of patent granted*  $\times$  *Average number of citations per patent* that may reflect the *Number of innovations*  $\times$  *Average level of innovation*, which may be taken as an indicator of the whole level of innovation in the sector.

<sup>85</sup>Home bias is the fact that a patent filed in a given country more often cites other patents of this same country. In other words American inventors more oftent cite American patents than others, German inventors more often cite German patents than others, etc.. In a dynamic point of view, the home bias is also reflected in the fact that Americans are quicker at citing other Americans, Germans are quicker at citing other Germans, etc. see, for instance, Griffith et al. (2007, [97]) .

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Figure 2.4: Shares of ICT patent citations over the period 1991-2003



Source: PATSTAT database, Johnson's Matrix

interpreted cautiously. Indeed, the fact that the weight of ICT sectors in patent citations is larger than their weight in R&D expenditure certainly reflects that ICT manufacturing industries have a strong propensity to patent, even if it still suggests a high level of innovation in these sectors.

On the other hand, the shares of citations received by patents that belong to ICT services sectors are too small to be reported here. This paradoxical result, in view of the importance of R&D in these sectors, emphasizes that patent data are not relevant to measure innovation in these sectors, because of their low propensity to protect innovation by patenting.

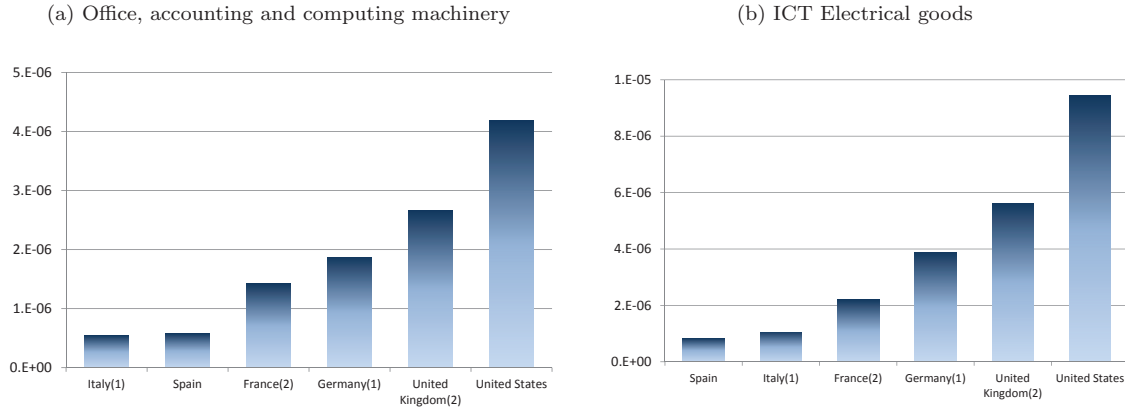
It is obviously unwise to quantify the pace of innovation and research productivity in the ICT manufacturing sector from patent data only. Notwithstanding, the importance of the activity in patenting and in R&D investment leads us to believe that this sector is particularly innovative and to confirm the first feature of a GPT which is that a GPT is subject to strong technical progress.

Figures 2.5 show the number of citations received per dollar invested in R&D in the two ICT sectors, *Office machine* and *ICT electrical goods*. For the calculus of this ratio we took an average lag of six years between R&D investment and the corresponding patent<sup>86</sup>. We take this measure as an indicator of the relative R&D productivity between countries in these sectors. Once again, this figure highlights the performance of the United States that is higher than the five biggest European countries since the number of citations per dollar invested is greater in U.S. than in the European countries. In both sectors, the ranking is almost the same except an inversion between Spain and Italy, which remain notwithstanding close in performance.

<sup>86</sup>In fact I compared the evolution of R&D investment and of citations and the peaks are approximatively staggered by six years. Moreover, as we took a ratio over a long period, any potential error is partly absorbed

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Figure 2.5: Number of patent citations per dollar\* invest in R&D



Sources: OECD, ANBERD, PATSTAT, Johnson concordance matrices

\*2005 dollars - constant prices and PPPs.

Notes: We count the sum of citations between 1993 and 2003 and the cumulated amount of R&D engaged between 1987 and 1997 (thus we take into account a 6 years delay in average).

(1) Because of the lack of data, for Italy and Germany the periods are 1997-2003 for citations and 1991-1997 for R&D.

(2) For all countries the disaggregation of the R&D is based on firms' main activities except for France and UK which is based on product field.

**Is ICT innovation slowing down?** For several years, we have reflected on the sustainability of the pace of ICT innovation. The question now is whether technological progress slowed in the ICT sector or not. Actually, two questions arise. The first is about the potential capacity for great inventions. In other words, can we expect other inventions as important as for example the internet? The second is about the pace of incremental innovation and can be exemplified by the following question. Is the Moore's law, formulated in 1965<sup>87</sup> that stipulates that the number of transistors that can be placed inexpensively in an integrated circuit doubles approximatively every two years, still valid?

To the first question, Gordon (2003 [91]) says there is indeed less major innovations and anticipates lower productivity growth potential in the future years than during the late 1990s because of the decreasing importance of the new innovations: for him, the development of Internet-enabled mobile phone is less important than Internet<sup>88</sup>. Nevertheless it is difficult to determine whether the source of radical innovation is exhausted or not in that field since the very nature of such innovations makes them less predictable. Concerning the second question, let us a glance at the patent citation data.

Figures 2.6 (a) and (b) that show the evolution of raw citations of ICT patents, emphasize an

<sup>87</sup>Published in an article April 19, 1965 in Electronics Magazine

<sup>88</sup>But we can moderate this remark in view of the "Internet" history, since "Internet", taken in its large definition including the network (corresponding to right use of the word Internet), the WWW, search engines etc., is made of a cluster of many inventions such as precisely the WWW, the TCP/IP, the research algorithm and so on, and internet-enabled mobile may be a part of them.

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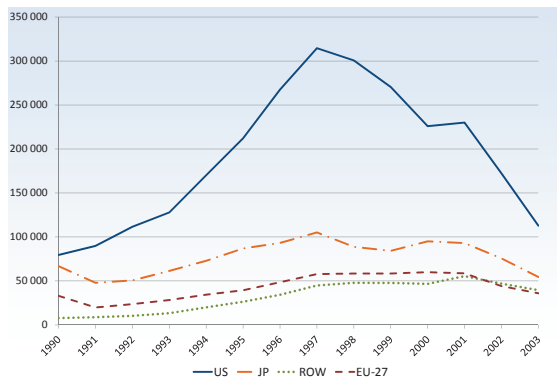
increase in ICT patent citations until 1997 but a decrease afterwards. This could reflect both a decrease in patent applications in the field of ICT and/or a decrease in the importance of previous ICT innovations.

However, the above comments on the limitations of such data lead us to look at the evolution of the share of ICT innovations in total patent quotes rather than their absolute numbers to control for possible changes in local behaviours concerning patenting. In this perspective, figure 2.6 (c) shows a stagnation rather than a real decrease since the second half of the 90s, even if at the end of the period the trend is not clear, given the sawtooth wave in figure (d) representing the growth rate of this share.

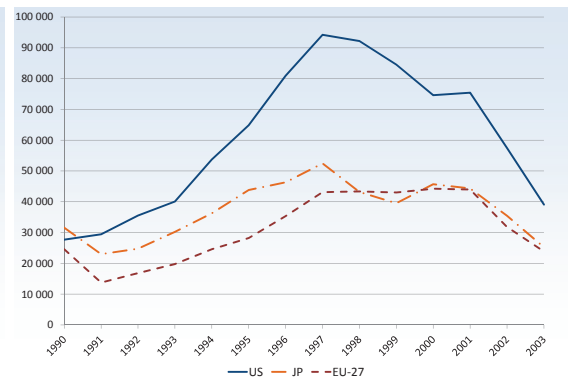
Therefore, the pace of ICT innovation appears to slowdown, nevertheless, as we explain in appendix 2.6.1, statistics based on patent data are especially relevant for ICT (physical) goods. Thus, these observations do not allow us to conclude that all ICT innovations are decreasing or stagnating since the mid 90s, and we must ask the question if ICT innovations are entering into a second phase where they are more services-related. In addition, admitting that ICT innovation slows down, even in ICT services (software), innovation can still be focused on improving their use. This is partly what we will investigate in the third part of this thesis. Finally, the period on which we focus is short and the ICT story is far from over and it would be therefore dangerous to make definitive affirmations about the pace of ICT innovation.

Figure 2.6: Trends of ICT patent citations

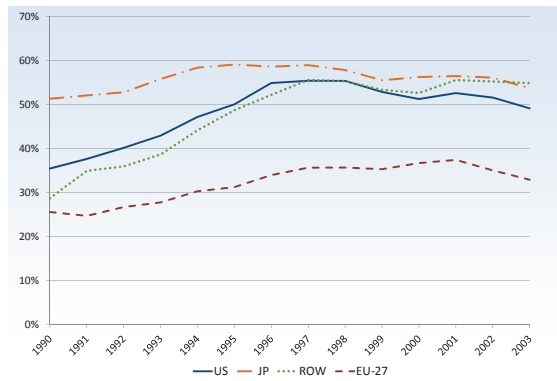
(a) Total number of citations received by ICT industries



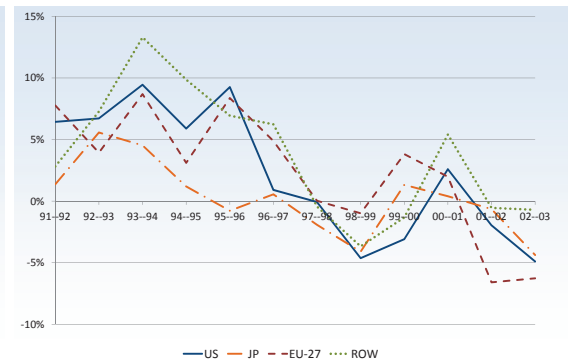
(b) Total number of foreign citations\*



(c) Share of ICT in total citations



(d) Growth rate of the ICT share in total citations



\*For Europe we report the sum of foreign citation per European country, thus the citations between European countries are taken into account here.

Source: Calculus from PATSTAT

### 2.4 ICT and knowledge externalities

Finally, in this third part, we deal with the issue of intersectoral externalities. More precisely, we assess the degree to which knowledge produced to innovate in the ICT sector can be used to innovate in the other sectors using forward patent citations data. Furthermore, we put ICT innovations into the perspective of a GPT, studying whether patent citation data may reveal the enabling features of the ICT. According to the way we allocate patents between sectors, we will see that the accumulated knowledge in the ICT sector is not necessarily a direct source of externalities for all the other sectors, even user sectors, and thus, the strategic complementarity that could exist between ICT producing and using industries should probably lie in a mechanism other than knowledge externalities.

#### 2.4.1 A knowledge flow matrix

One of the features of innovation is that it generates positive externalities by producing non-exclusive knowledge that can be used by other agents in other countries and other sectors. These externalities are fundamental in the process of growth based on innovation.

As ICTs have been recognized as engines of growth during recent decades as well as very progressive technologies, in this section we investigate the role of such mechanisms linked to knowledge externalities. We try to determine whether knowledge accumulated to innovate in ICT sectors may increase the return from R&D in other sectors. Actually, in concrete terms, we investigate whether knowledge used to reduce the size of a processor or to improve the capacity of a harddrive disk is useful for the automobile sector or the agricultural machinery sector.

In order to deal with this issue, we analyse data on patent citation flows using the patent citation matrix mentioned above. This matrix is described in detail in appendix 2.6.2, here we just sum up the main characteristics.

The main features and originalities of this matrix are threefold:

1. It represents patent citation flows (from a cited to a citing patent);
2. It refers to economic sectors instead of technology classes, like traditional patent data;
3. It represents knowledge flows between both countries and sectors.

Its construction is based on the Johnson methodology (D. K. Johnson, 2002 [130]) that defines the OECD technology concordance (OTC) to translate International Patent Class (IPC) into economic

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sectors. The OTC is actually another version of the Yale technology concordance. The patent data come from the PATSTAT database which is the worldwide patent statistical database of the European Patent Office (EPO)<sup>89</sup>.

Thus, this matrix captures knowledge flows between sectors and between countries, and combines these two dimensions, i.e., it describes knowledge flows between a sector in one country and a possibly different sector in a possibly different country.

The measurement challenge that this combination of dimensions provides was tackled by combining two ideas:

- The first one relates to patent citations, which represent a knowledge flow from the cited to the citing patent<sup>90</sup>;
- The second idea relates to users and producers of the innovation.

On one hand, in the user-producer relationship, we relied on the Yale concordance matrix. This matrix is based on Canadian patent data, and it assigns, on the basis of a technological classification, the number of sectors that are the most likely origin of an invention, as well as the number of sectors that are the most likely users of that invention. By combining large amounts of individual inventions (patents), a statistical distribution (matrix) can be constructed in which “invention producing” sectors provide knowledge to “invention using” sectors. The most likely “invention producing” sectors are defined as the Industry Of Manufacturing (IOM) sector and the most likely “invention using” sectors are called Sector Of Use (SOU).

On the other hand, as we said above, we use to measure knowledge flows between countries information on patent citations. A patent citation identifies a specific citing and cited patent, and this contains information about the location of the inventor(s) and owner(s). Because there is a time lag between the cited and citing patent, a third dimension, diffusion time, could also be added to the analysis.

The resulting matrix is 3-dimensional, i.e., (cited sector within a country)-by-(citing sector within a country)-by time. This type of matrix can thus be used here to assess intersectoral and international

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<sup>89</sup>More precisely we use data on patents for which the authority is USPTO, EPO or WIPO for homogeneity reasons. See appendix 2.6.1

<sup>90</sup>For the sake of clarity, through a misuse of language, we talk about patents that belong to a given IOM or SOU that cite other patents that belong to another IOM or SOU. However, patents correspond more exactly to patent families, i.e. groups of specific patents that cover a single invention. So we will use the term patent as a shortcut for patent family. Secondly, we directly allocate citations between IPC to citations between economic sectors. Thus patents do not appear as identified and indivisible identities in our matrices.

externalities. In particular, the spillover matrix is intended to deal with the two following points:

1. The R&D expenditures of a sector  $i$  in a country  $j$  have an effect on the efficiency of R&D in other sectors and/or in other countries. Similarly, the efficiency of R&D in sector  $i$  in country  $j$  is affected by R&D that is undertaken in other sectors and/or in other countries.
2. The R&D expenditures of sector  $i$  in country  $j$  are embodied in products (or services) produced in sector  $i$  in country  $j$ . These products are exported to other countries and may be used as inputs in other sectors. This may affect the productivity of these buying-sectors.

From this matrix we can deduce some characteristics of the externalities resulting from ICT innovations. In this section, first we focus on international ICT externalities and, in the second part, we will focus on intersectoral externalities and, more specifically, on the knowledge flows from the ICT industries to the other sectors. The underlying idea is to assess the extent to which innovation in ICT impacts innovation in other sectors, i.e. we study the general use or the degree of concentration of the knowledge created and used to innovate in the ICT sector, calculating how often other sectors cite patents that belong to ICT industries and determining the distribution of citations between sectors. In this way, we investigate whether the knowledge used for ICT innovations is general purpose. We will also discuss the conclusions that may be made on whether we can consider ICT as GPT.

### 2.4.2 International ICT knowledge externalities

Table 2.3 gives the percentage of citations issued by a region  $i$  and received by a region  $j$  in the total number of citations. For example, the number of times a European patent cites a U.S. patent represents 6.47% of the total number of patent citations.

It shows that the U.S. represent more than a half of total patent citations<sup>91</sup> both as a citing country and as a cited country. And, with Japan, they represent more than 70% of issued or received citations. The table shows also that the European countries are citing countries rather than cited countries. This leads us to think that they are rather recipients than issuers of ICT externalities.

Figures 2.7 (a) and (b) respectively depict the destinations and the origins of ICT knowledge externalities in percentage of total ICT knowledge externalities that are respectively issued or received by four regions U.S., Japan, Europe and the rest of the world (ROW)<sup>92</sup>. Figure (a) represents, for each

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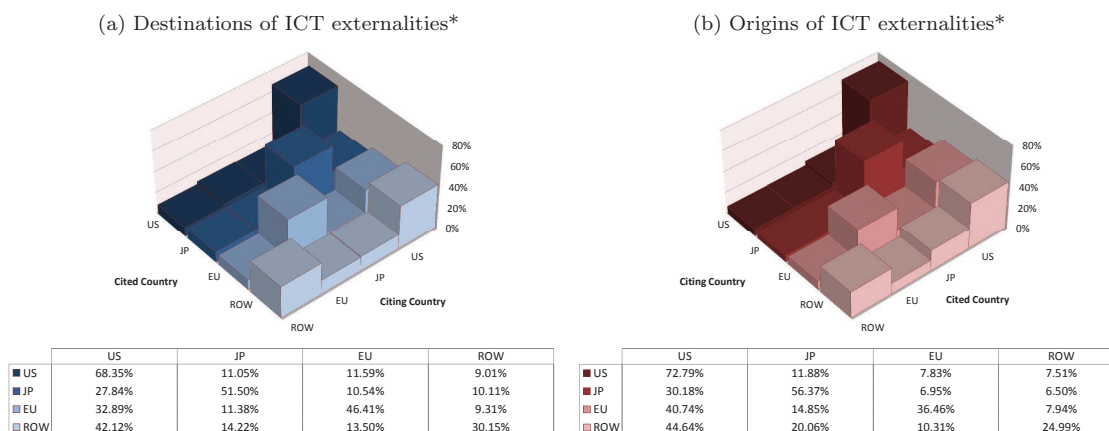
<sup>91</sup>In the patent offices that are taken into account, i.e. WIPO, EPO and USPTO

<sup>92</sup>The figures 2.13 and 2.14 provide similar representations distinguishing each EU country. Figure 2.12 shows the number of citations between each country.



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Figure 2.7: Destination and origins of ICT knowledge flows



Note:

- The figure (a) represents, for each region  $i$  the percentage of the citations received by a region  $i$  from  $j$  in the total citations received by  $i$ . For instance, taking Europe as  $i$ , in the total patent citations received by European countries, 32.89% are issued by the U.S., 11.38% by Japan, 46.41% by Europe and 9.31% by the ROW.
- The figure (b) represents, for each region  $i$  the percentage of the citations issued by a region  $i$  to  $j$  in the total citations issued by  $i$ . For instance, taking Europe as  $i$ , in the total patent citations issued by European countries, 40.74% are received by the U.S., 14.85% by Japan, 36.46% by Europe and 7.94% by the ROW.

Sources: PATSTAT, Johnson matrices

\*percentage of the total citations of respectively the cited and citing region between 1990-2003 for fig. a and b (The total of each color variance is set to 100, i.e. each line of tables is set to 100)

region  $i$ , the percentage of the citations issued by a region  $j$  to  $i$  in the total citations received by  $i$ . For instance, taking Europe as  $i$ , in the total patent citations received by European countries, 32.89% are issued by the U.S., 11.38% by Japan, 46.41% by Europe and 9.31% by the ROW<sup>93</sup>.

These figures also highlight the “home bias”<sup>94</sup> of patent citations with the highest level of values on the diagonal. Moreover, they show the U.S. importance for each region both as a destination of ICT externalities (the number of times a region’s patents are cited by US) and as an origin of ICT knowledge externalities (the number of times a region’s patents cite US patents).

Figure (b) emphasizes another remarkable fact which is that, despite of this home preference, Europe cites more U.S. (40.74%) than itself (36.46%). Actually this observation comes from that there is no European preference in patent citations. A European country cites itself more than the others but it does not cite other European countries more than the others. Furthermore the sum of “home bias” for each European country is not enough to overpass the citations issued to patents from the United States.

<sup>93</sup>The sum of the elements of each line equals 100%

<sup>94</sup>The fact that a country cites itself more than the others

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Table 2.3: ICT knowledge flows between aggregated world regions between 1990-2003

		Citing				Total
		US	JP	EU	ROW	
Cited	US	38.16%	6.17%	6.47%	5.03%	55.82%
	JP	6.23%	11.52%	2.36%	2.26%	22.36%
	EU	4.10%	1.42%	5.79%	1.16%	12.47%
	ROW	3.94%	1.33%	1.26%	2.82%	9.34%
Total		52.42%	20.43%	15.88%	11.27%	100%

Note: This table gives the percentage of the citations issued by a region  $i$  and received by a region  $j$  in the total number of citations. For example, the number of times a European patent cites a U.S. patent represents 6.47% of the total number of patent citations.

In order to compare innovation performance, on figure 2.8 we plot the ratio received citations/ issued citations over the period 1991-2003. The continuous lines plot the ratio for citations of ICT patents whereas the dotted lines represent the ratio for citations that do not concern ICT (sectors are defined here as IOM).

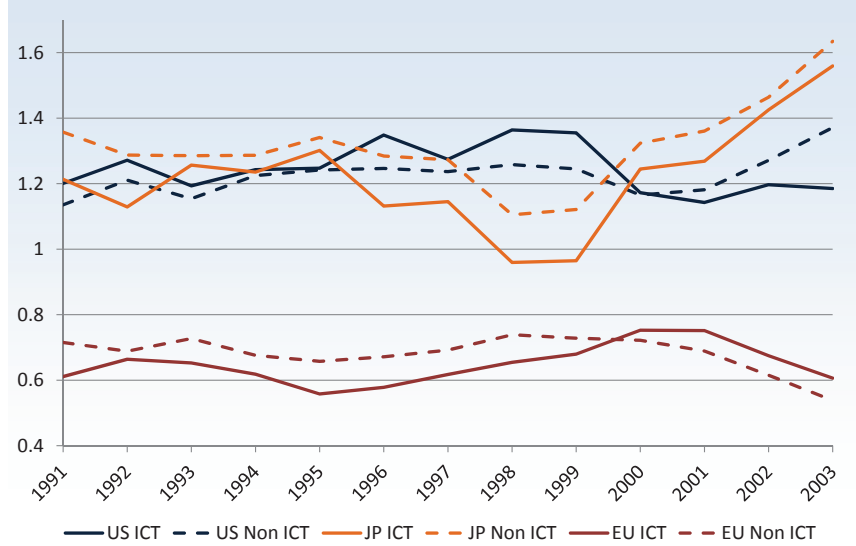
Moreover we only take into account foreign citations. Indeed, the more the home bias is important, the more the ratio is close to one, since home citations appear as received in the numerator and as issuing in the denominator. Therefore, in order to be able to compare countries, we removed these home citations<sup>95</sup>. Nevertheless, this measure is more a qualitative measure than a quantitative one.

Figure 2.8 shows that Europe has cited more than it has received citations from abroad for all patents that were filed between 1991 and 2003, both in ICT industries and in the other sectors, whereas for Japan and U.S. the ratio is reversed. Furthermore, except in U.S., this ratio is slightly lower regarding ICT industries than in the other sectors. On the other hand, we observe that Europe caught up during the second half of the 90s in ICT industries but after 2000 the ratio fell while it increased in Japan and it remained constant in ICT industries after a short fall around 2000 in U.S..

Therefore, the figure suggests that European patents are globally of lower quality than American and Japanese ones and more so in ICT sectors. In addition, in the later years of the period, it seems that it continues to deteriorate in Europe. Notwithstanding, we must remain cautious in interpreting this indicator and further investigations should be made on its validity. Certainly, the relative position, above or under 1, as well as the evolution may have significations but the degree of variation (the magnitude) is more difficult to interpret.

<sup>95</sup>For Europe, we do not remove intra-EU citations: we keep the citations between EU-countries but we delete countries autocitations.

Figure 2.8: Ratio received citations/issued citations



Sources: Calculus from PATSTAT and Johnson matrices

### 2.4.3 Is knowledge for ICT innovations general purpose?

In this section, we deal with the issue of intersectoral externalities. In particular, we investigate two main features of ICT innovations:

1. Firstly, we try to assess the degree to which knowledge created by ICT innovation could be useful in other sectors and especially whether this knowledge is spread across sectors. Then this point fits with the pervasiveness of GPT.
2. Secondly, we try to determine if the use of ICT-linked innovations induces an increase in its own innovation. This point fits with the enabling feature of GPT.

**The general use of knowledge for ICT innovation** In order to assess the general use of knowledge created by ICT innovation, we proceed in two steps. The first is a short graphical analysis and aims to illustrate the issue, whereas the second is analytical and provides more rational evidence.

Figures 2.9 show the number of citations received by patents whose IOM are the four ICT sectors and issued by patents that belong to respectively non-ICT IOM (fig. a) and SOU (fig. b). In these figures we exclude ICT industries because the frequency of citations of ICT industries by themselves

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is too high to be represented here. We can interpret these figures like this: the more a sector cites an ICT sector, the more it is technologically close to the ICT industry as it uses the same knowledge as ICT industry to innovate.

Depending on whether we allocate citing patents to their IOM or their SOU (keeping the cited ICT patent to its ICT IOM), the distribution of citations is not the same. Indeed, we observe that, in the case of a citing SOU, citations are slightly less concentrated among few sectors than in the case of citing IOM. This means that patents that cite patents produced in ICT sector are produced in only few sectors but used in more sectors. Therefore, the “generality” of ICT-knowledge based innovation is largest in terms of use than in terms of production.

Moreover, in these two cases, the sectors that are closer to ICT are not exactly the same. When we allocate citing patents to their IOM, the five closest sectors to the ICT-IOM are *Non-ICT electrical goods, Agriculture and industrial machinery, Chemicals, Transport equipment industry and Other manufacturers*. In the other case, when we attribute the citing patent to its SOU, the five closest sectors to the ICT-IOM are *Non-ICT electrical goods, Non market health services, Transport equipment, Other non-ICT market services and Agriculture and industrial machinery*. In particular the services sectors could be defined as intensive users of innovation based on ICT-knowledge.

Now, in order to have a more rational point of view and to be able to compare the ICT sector to others, we construct a Herfindahl index as in Trajtenberg et al. (1997 [219]) and in Hall and Trajtenberg, (2004 [110]), in which, instead of technology classes, we focus on IOM and SOU. The aim is to measure the extent to which follow-up technical advances are spread across different sectors. The underlying idea could be explained by the following example given in Trajtenber et al. (1997 [219]):

“If a patent in solid-state physics is cited by later patents in chemistry, in superconductivity and in medical instrumentation, we would regard it as more general, and hence more basic, than a similar patent that received the same number of citations but all or most of them belong to the same field”

The Herfindahl index is defined as:

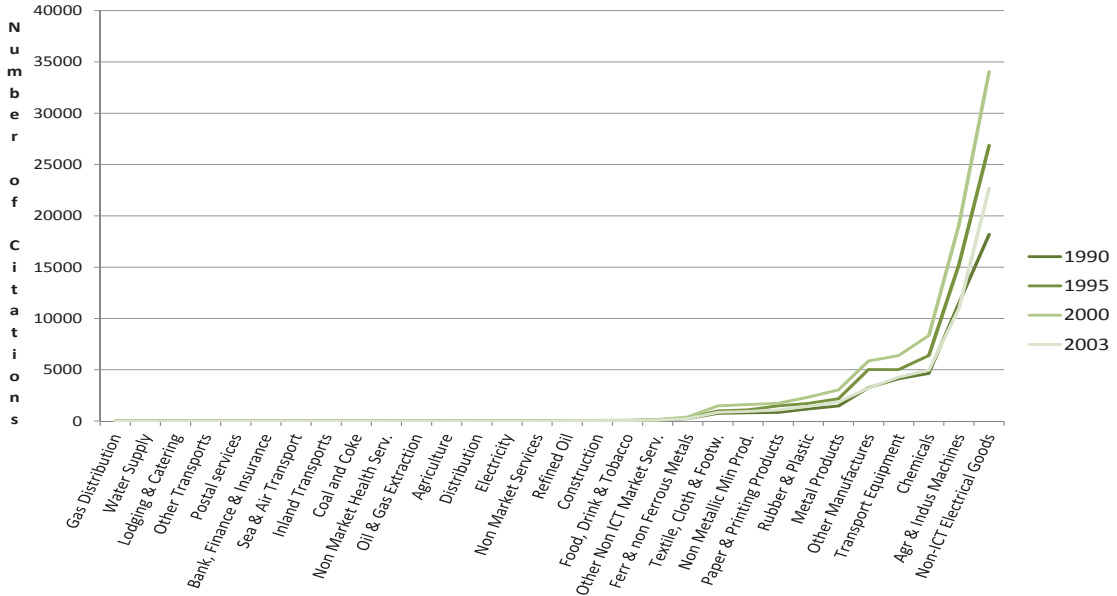
$$G_i = 1 - \sum_{j=1}^n c_{ij}^2$$

where  $c_{ij}$  denotes the percentage of the citations issued by the sector  $j$  to  $i$  in the total citations received by sector  $i$  by the  $n$  sectors that composed the economy  $c_{ij} = \frac{C_{ij}}{\sum_{i=1}^n C_{ij}}$ . This index is between 0 and 1. When citations are homogenously distributed over an infinite number of sectors,

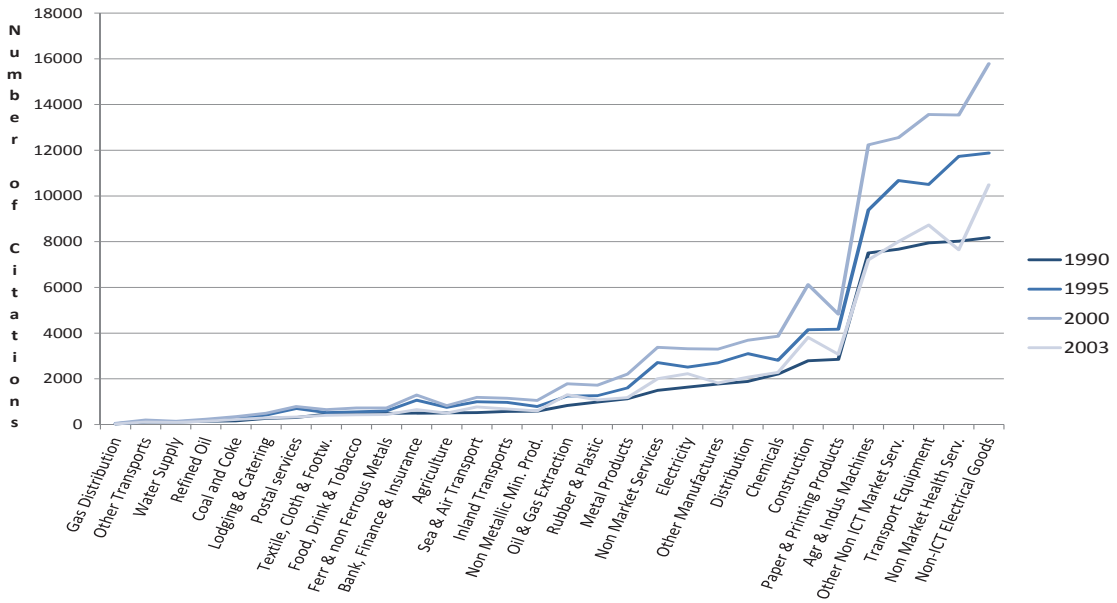
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Figure 2.9: Knowledge externalities based on patent citations matrices

(a) ICT industry and other sectors as IOM



(b) ICT industry as IOM and other sectors as SOU



Sources: calculus from PATSTAT and Johnson matrices

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the Herfindahl index converges to one. Moreover, the highest is the generality score, the largest is the impact of a patent that belongs to a given sector  $i$ . Indeed “a high generality score suggests that the patent had a widespread impact, since it influenced subsequent innovations in a variety of fields.” (OECD, 2009 [239]) Conversely lower values represent higher concentrations.

Some limitations of this indicator must be taken into account:

In our sample, the generality measure could be biased when the citation frequency is small:

“As shown by Hall and Trajtenberg (2004 [110]), the generality measure is biased downward when the number of patents on which it is based is small. Basically, if there is some “true” probability of a random patent being in one of many classes, the true concentration may be low; if very few patents are actually observed, they can only be in a few classes, and the measured concentration will be high. The indicator needs to be adjusted by the size of observations” (OECD, 2009 [239])

However, applying a correction such as in Hall (2005 [109]), defining  $\tilde{G}_i = \frac{N_i}{N_i-1}G_i$  where  $N_i$  is the number of citations observed, does not significantly change our results<sup>96</sup>.

A second limitation is due to the consistency of the relative disaggregation of sectors. This problem is similar to those encountered by Hall and Trajtenberg (2004 [110]) with their classification system. Indeed, in order to do a consistent comparison, the disaggregation level of each sector must be similar.

Finally, the propensity to patent is very different between sectors, especially between the manufacturing and service sectors. Therefore, the propensity to cite patents, and thus reveal knowledge on which the sector’s innovations are based, is different between sectors. For instance, on one hand, consider a sector that protects its innovations by patenting and, on the other hand, consider a second sector that protects its innovations by industrial secrecy. Suppose also that these two sectors use the knowledge created by the ICT sectors to the same degree. Such a generality index, based only on the distribution of patent citations, will lead us to deduce that knowledge created by ICT industries is only useful for the first sector and that this knowledge is more specific than in reality. Therefore, we construct, in appendix 2.6.3, an alternative Herfindahl index that takes into account this observation by normalizing the total citations issued by each sector. This alternative index nevertheless still has drawbacks since it assumes that all sectors use knowledge to the same degree whereas some sectors

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<sup>96</sup>In our matrix, citations are divisible, so this correction is less justified. Hall and Trajtenberg do not apply this correction in their sectoral approach.

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may actually not innovate. The truth is certainly between the two types of model and, unfortunately, the gap between them is great, so, further investigations in that direction are necessary.

**The results** of the Herfindahl index according to sectors are reported in table 2.4. Here we examine here four measures of generality depending on whether cited and citing patents are allocated to their industry of manufacture or to their industry of use.

Globally, table 2.4 shows that patents whose industries of manufacture or sectors of use are the ICT industries are cited by patents that are produced or used in only few sectors. Whether considered as an industry of manufacture or as a sector of use, the four ICT sectors are always in the six most knowledge specific sectors, despite their large numbers of patent and citations. We can interpret the results depending on the case as follows:

In the first case (IOM-IOM reported in the first column of table 2.4), the fact that an ICT sector as industry of manufacture is cited by only few other industries of manufacture reflects that knowledge used to produce ICT goods is not used to produce other types of goods.

The second column reports the IOM-SOU results where the cited sectors represent industries of manufacture of cited patents and citing sectors represent the sector of use of the citing patent. The fact that ICT patents are cited by patents that are used in only few sectors is less easy to understand. In fact, according to the previous results, citing patents should mostly be patents produced by the ICT sector which is supposed to produce broadly used goods. So the first inference leads us to expect numerous SOU for ICT patents. Actually, this paradox reflects the fact that patents that cite ICT-IOM sectors relate mainly to innovations on ICT intermediate consumption goods that are mainly used in the ICT industry. In other words, ICT innovations should relate mainly to ICT components (such as semiconductors) that are used only by ICT industries and not on final ICT goods (the entire computer) that are used more broadly across sectors. In fact, we may suppose that patents on semiconductors which are produced by an ICT industry are mainly cited by other patents on semiconductors that are also used in ICT industries. Therefore patent citation data seem to be unable to provide us evidence of the pervasiveness of ICT innovations.

Moreover, the specificity of innovations whose sectors of use are the ICT sectors could arise from the same cause since the share of innovations whose both IOM and SOU are the ICT sectors is important. This should be the case if most of patents are for intermediate goods that are produced and used in the ICT industry (as semiconductors).

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Consequently, our results suggest a priori that the knowledge used for ICT inventions is very ICT specific, furthermore, it seems very difficult to highlight the pervasiveness of ICT knowledge as well as co-invention mechanisms in downstream sectors using patent citation data.

However, the results according to the alternative generality index, given in table 2.9 in appendix 2.6.3, lead us to moderate our conclusion about the specificity of ICT knowledge. We can indeed see that the results are strongly different from the previous ones and especially that the relative generality of knowledge (with respect to other sectors) of the two ICT manufacturing sectors, which represent almost the totality of ICT patents, is largely improved. This change reflects that ICT patents are relatively more cited by sectors that make fewer citations than the other sectors. Therefore, it shows that patent citations data are probably insufficient to capture GPT properties of ICT. One reason for that could be the fact that innovations in service sectors, that are intensive users of ICT, are not often patentable.

**Growth of innovation (in patents) in ICT invention user sectors** A way to ascertain that ICT innovations spur innovation in user sectors is to look at whether the growth rate of innovation (reflected by the growth rate of citations received) in sectors is positively related to the use of ICT-related innovations.

Knowing that a patent that cites a patent belonging to an ICT industry as an IOM could be considered as an ICT-related invention, and considering a given SOU  $i$ , the more this latter sector cites ICT industries as IOM compared to other sectors, the more the share of ICT-related inventions used in its total use of inventions is high, therefore, the more it should benefit from the great level of ICT innovation rate. Moreover, if the use of ICT-related inventions enables a sector to innovate, the growth rate of innovation should be higher as the share of the use of ICT-related inventions is high in that sector.

In that perspective, on figure 2.10 we show the sectors according to the following method:

- First we define the relative importance of the use of ICT-related inventions in sector  $i$  as the share of the citations received by the ICT industries as IOM and issued by the sector  $i$  as SOU.  $s_{ICT,i} = \frac{C_{ICT,i}}{\sum_{j=1}^n C_{j,i}}$  where  $C_{j,i}$  is the number of citations received by the IOM  $j$  and issued by the SOU  $i$  during the period. We report this value on the abscissa.
- In the ordinate, we define the growth rate of innovation of the sector  $i$  as the average annual growth rate of total citations received by  $i$  as an IOM.



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Table 2.4: Generality Herfindahl index (matrices defined according to Cited-Citing)

IOM-IOM		IOM-SOU		SOU-IOM		SOU-SOU	
Cited Sector	G	Cited Sector	G	Cited Sector	G	Cited Sector	G
<i>Telecommunications</i>	<b>0.48</b>	<i>Telecommunications</i>	<b>0.62</b>	<i>Telecommunications</i>	<b>0.37</b>	<i>Telecommunications</i>	<b>0.58</b>
Agriculture	0.54	Non Market Services	0.64	<i>ICT Elec Goods</i>	<b>0.51</b>	<i>Computer Services</i>	<b>0.62</b>
<i>ICT Elec Goods</i>	<b>0.54</b>	<i>Computer Services</i>	<b>0.64</b>	Chemicals	0.56	Non market health services	0.65
Chemicals	0.55	Transport Equipment	0.64	<i>Office Machines</i>	<b>0.60</b>	<i>Office Machines</i>	<b>0.68</b>
<i>Computer Services</i>	<b>0.59</b>	<i>ICT Elec Goods</i>	<b>0.68</b>	<i>Computer Services</i>	<b>0.62</b>	<i>ICT Elec Goods</i>	<b>0.69</b>
<i>Office Machines</i>	<b>0.62</b>	<i>Office Machines</i>	<b>0.70</b>	Postal services	0.68	Agriculture	0.72
Non market health services	0.66	Non market health services	0.73	Sea & Air Transport	0.70	Postal services	0.78
Oil & Gas Extraction	0.69	Food, Drink & Tobacco	0.77	Bank, Finance & Insurance	0.71	Transport Equipment	0.79
Transport Equipment	0.69	Agriculture	0.78	Oil & Gas Extraction	0.72	Bank, Finance & Insurance	0.80
Food, Drink & Tobacco	0.73	Chemicals	0.81	Water Supply	0.72	Food, Drink & Tobacco	0.83
Sea & Air Transport	0.73	Sea & Air Transport	0.84	Refined Oil	0.72	Non Market Services	0.84
Refined Oil	0.73	Oil & Gas Extraction	0.84	Non-ICT Electrical Goods	0.75	Oil & Gas Extraction	0.84
Agr & Indus Machines	0.75	Non-ICT Electrical Goods	0.84	Transport Equipment	0.76	Other Non ICT Market Services	0.85
Non-ICT Electrical Goods	0.76	Other Non ICT Market Services	0.88	Agriculture	0.77	Chemicals	0.86
Coal and Coke	0.78	Other Manufactures	0.89	Agr & Indus Machines	0.77	Sea & Air Transport	0.86
Electricity	0.80	Refined Oil	0.89	Coal and Coke	0.77	Non-ICT Electrical Goods	0.87
Inland Transports	0.81	Electricity	0.89	Ferr & non Ferrous Metals	0.77	Agr & Indus Machines	0.88
Other Non ICT Market Services	0.82	Construction	0.82	Non market health services	0.78	Rubber & Plastic	0.88
Non Market Services	0.83	Tex., Cloth & Footw.	0.90	Electricity	0.79	Non Metallic Min Products	0.89
Ferr & non Ferrous Metals	0.83	Non Metallic Min Products	0.91	Gas Distribution	0.79	Construction	0.89
Other Manufactures	0.84	Ferr & non Ferrous Metals	0.91	Food, Drink & Tobacco	0.81	Paper & Printing Products	0.89
Metal Products	0.85	Distribution	0.92	Non Market Services	0.81	Tex., Cloth & Footw.	0.89
Non Metallic Min Products	0.86	Coal and Coke	0.92	Other Non ICT Market Services	0.82	Metal Products	0.89
Tex., Cloth & Footw.	0.87	Metal Products	0.92	Rubber & Plastic	0.83	Refined Oil	0.90
Rubber & Plastic	0.88	Paper & Printing Products	0.92	Non Metallic Min Products	0.83	Gas Distribution	0.91
Paper & Printing Products	0.88	Agr & Indus Machines	0.92	Paper & Printing Products	0.84	Ferr & non Ferrous Metals	0.91
Construction	0.88	Rubber & Plastic	0.93	Metal Products	0.85	Coal and Coke	0.91
Distribution	0.89	Inland Transports	0.94	Other Transports	0.85	Water Supply	0.92
Gas Distribution	--	Gas Distribution	--	Tex., Cloth & Footw.	0.85	Distribution	0.92
Water Supply	--	Water Supply	--	Lodging & Catering	0.85	Electricity	0.92
Lodging & Catering	--	Lodging & Catering	--	Inland Transports	0.85	Inland Transports	0.93
Other Transports	--	Other Transports	--	Other Manufactures	0.86	Lodging & Catering	0.93
Postal services	--	Postal services	--	Construction	0.86	Other Manufactures	0.93
Bank, Finance & Insurance	--	Bank, Finance & Insurance	--	Distribution	0.87	Other Transports	0.94

*Calculus based on knowledge matrix over the period 1990-2003*

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In the figure, we distinguish three categories of sectors: (i) The six sectors in green are sectors in which no patents are attributed to them as IOM in the concordance matrix. We obviously exclude them from the linear regression and our analysis. (ii) We report in blue all the other non-ICT industries and (iii) in red the four ICT sectors. This figure appears to highlight a positive relationship between these two variables. The red line shows the results of the linear regression, considering all the sectors<sup>97</sup>. It reveals the positive relationship between growth of innovation and the use of ICT realted inventions<sup>98</sup> but the four ICT sectors, which are reported in red, favorably affect this relationship. Therefore, in order to determine whether this relationship still exists in other (Non-ICT) sectors only, we show the results of the regression, excluding the ICT sectors in blue. We show that the slope does not change a lot but the correlation coefficient is weaker (the relation is still significant at 5%<sup>99</sup>). Therefore, with this analysis, co-invention mechanisms are not really proved.

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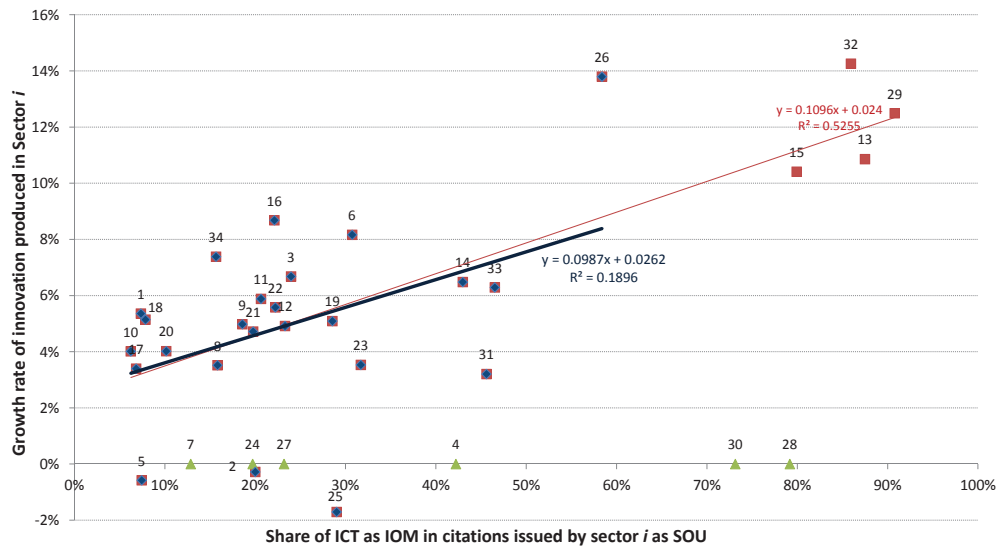
<sup>97</sup>Obviously except the six sectors in green that are not the IOM of any patent

<sup>98</sup> $R^2 = 0.525$ ;  $P - value = 0.000$

<sup>99</sup>P-value=0.033

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Figure 2.10: Relationship between growth of innovation and the relative use of ICT related inventions (between 1991-2000)



1 Agriculture	10 Chemicals	20 Rubber & Plastic	30 Bank, Finance & Insurance
2 Coal and Coke	11 Metal Products	21 Other Manufactures	31 Other Non ICT Market Services
3 Oil & Gas Extraction	12 Agr & Indus Machines	22 Construction	32 Computer Services
4 Gas Distribution	13 Office Machines	23 Distribution	33 Non Market Services
5 Refined Oil	14 Non-ICT Electrical Goods	24 Lodging & Catering	34 Non market health services
6 Electricity	15 ICT Elec Goods	25 Inland Transports	
7 Water Supply	16 Transport Equipment	26 Sea & Air Transport	
8 Ferr & non Ferrous Metals	17 Food, Drink & Tobacco	27 Other Transports	
9 Non Metallic Min Products	18 Tex., Cloth & Footw.	28 Postal services	
	19 Paper & Printing Products	29 Telecommunications	

### 2.5 Conclusion

In this chapter we investigated ICT innovations with two objectives:

- The first was to depict the nature of technical progress in ICT and recall the sequence of great inventions in that field;
- The second was to place ICT in the perspective of General Purpose Technologies. In particular, we examine whether patent data may provide evidence of GPT features.
- In parallel with these previous objectives, the third was to understand how the U.S. became a leader in ICT and how high they outstrip Europe in ICT innovation;

Through our short historical review, we saw that U.S. was better than Europe at inventing ICT, partly thanks to a better cooperation between Government, University and Private firms and individual inventors. This cooperation resulted by the coordination by the Government of grant projects involving many actors, such as SAGE or ARPANET. Moreover, the agents involved in these projects were able to capitalize on their experience and, subsequently, they were able to develop civil applications (Supercomputers, SABRE, NSFNet) and highly innovative firms were founded or have grown, such as Bell, IBM, Cray Research Inc., Cisco Systems etc..

On the contrary, Europe failed to establish an enabling environment for innovation and for developing firms in that field. First, the strategy of secrecy adopted in United Kingdom concerning the knowledge acquired during the World War II in coding and computer science until 1975 paralysed the process of innovation and the creation of enterprise in a particularly advanced country. Secondly, later, the lack of European governance, added to the choice to focus spending on other priorities during the oil crisis, thwarted the plan to build a competitive European computer industry in the manner of Airbus (CII and Unidata).

Nevertheless, all European experiences were not all failures. Indeed, despite the fact that European countries have not managed to position themselves as real leaders, Europe has not been completely overtaken by the U.S.. Furthermore, if some of the paths taken by European countries were not sustainable, they provided valuable knowledge in other contexts. In particular, even if the cost of obsolescence of the Telenet and the Minitel was high with the arrival of Internet in France, the experience based on the use of this technology was largely transferable to the use of Internet, since the services offered by both systems were very close.

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Even so, it is noticeable that the United States were a driving force at all stages of ICT development:

- Conception and the production of computing machinery;
- Scientific and commercial applications;
- Userfriendliness;
- Telecommunication networks and their use (internet services).

Next, analysis of contemporary data on R&D expenditure and patent citations related to ICT industries still highlight the preeminence of the United States in that field. In particular, we have seen that the United States, as well as Japan, are more R&D intensive in the big sectors compared to Europe. Thus, the combination of the share of production and the R&D intensity of the ICT sectors make U.S. and Japan globally more ICT-R&D intensive.

Moreover, micro data emphasize the clustering of R&D since a large number of the biggest R&D investors in ICT are located in California. In particular, this cluster groups together most of the ICT sectors (especially computer hardware and software, telecommunication equipment and internet industries). On the contrary, in Europe, the biggest R&D investors in the different ICT industries are disseminated. Therefore we can ask whether clustering of some ICT sectors is advisable in Europe or, at least, whether European research in ICT needs to be “wired”. The high level of necessary investment may imply a coordinate action between European countries. Indeed, in view of the size of the U.S. and Japan, we can also ask whether one European country alone could struggle to afford such investment. Nothing is less certain, since UK already reached the technological frontier during the war and France was also a leading country in the telecommunication sector. That is why the question should rather be whether regional specialization is optimal or not for ICT-R&D coordination.

Now, concerning the GPT features of ICT, we found evidence of the first GPT property which is that a GPT present strong potential for development. However, we saw that it is difficult to find evidence in patent data for the other features. If the data appear to demonstrate a strong technical progress in this sector<sup>100</sup>, the two other features, the pervasiveness and the enabling ability of ICT,

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<sup>100</sup>However, as technical progress makes sense by the improvement of the utility provided by the good or the service that embeds it, it is necessary to study whether ICTs’ improvement has resulted in the increase of their usefulness and more specifically whether it has improved the production process in industries where ICT are use intensively. Doubling the speed of a processor is not an end per se and does not necessarily lead to the doubling of the processor’s final utility. We discuss this issue in the next chapter.

are less obvious. Three reasons may be at the origin of these results that means we should be very caution in interpreting them:

1. The limitations of the relevance of patent data to measure innovation. Patent data's cover of innovative activity is imperfect, as not all innovations are patented or patentable as Hall and Trajtenberg (2004 [110]) told us. As we have seen, the propension to patent may be very different depending on the sector. In particular, complementary innovation may not be patentable. Indeed, we will see in the third part of this thesis that ICT co-innovations consist mainly of organizational innovations or other innovations that do not fill the common definition of an invention. Like David, we can make the analogy with the dynamo: the dynamo led to a patent filed by the inventor Z. Gramme but the reorganization of the machines through the unit drive system did not give rise to further patents. It is therefore dangerous to use patent data without taking this into consideration. For this purpose, we constructed a weighted generality measure and we obtained really different results. However, the assumptions underlying this measure are also subject to limitations.
2. The relevance of the use of the Johnson/Yale matrix. In particular because of two limitations in this matrix as far we are concerned:
  - (a) Firstly, the Johnson matrix is only based on data from the Canadian Intellectual Property Office between 1972 and 1995 and, therefore, the rigidity on the citation distribution structure could lead us to underestimate the generalization of ICT externalities.
  - (b) Furthermore, the notion of Sector Of Use (SOU) may also not be really appropriate. Indeed, a sector of use represents the sector that uses the technical solution given by the patent, but not the final user of the good that embeds this technical solution (patents on ICT components are mainly used in ICT industries). So this definition does not help us to reveal the downstream innovation mechanism. Probably this definition is more suitable to study externalities between ICT industries, in any case, we should probably distinguish between intermediate use and final use.
3. Externalities of ICT innovations towards the other sectors may not rely on direct knowledge externalities. Indeed, even if the knowledge used for ICT innovation is specific, ICT research may have an impact on other sectors because the technological complementarities do not necessarily

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involve knowledge externalities: let us return to the dynamo, the knowledge used to optimize the placement of machines had no connection with that used to invent the dynamo. In other words, Faraday's law of induction was not used to reorganize the production process but made it possible! Therefore, further investigation must be done in the field of complementary innovation and this is the subject of the third part of this thesis.

These remarks lead us to argue that the innovative strategic complementarity between a GPT producer and a GPT user must be taken in its broadest sense. We must take into account all types of innovative activities, obviously including R&D expenditure but also organizational and other types of expenditure that aim to improve the production. If we group all these innovative efforts under the name of intangible investments, from that point of view, ICT-producing industries are an intangible strategic complement to ICT-using industries, that is to say that ICTs as enabling technologies, may work in different ways:

In particular, ICT can lead to increase in intangible investment incentive in using-sectors by:

- Improving intangible productivity in these sectors since ICT may be:
  - A research tool (such as computer) or included in a research tool (such as in MRI scanner), therefore the more these tools are performant, the more the research productivity is increased,
  - Incorporated in the final good in the using sector, i.e. an intermediate consumption (such as a GPS in a car),
  - A source of knowledge externalities;
- Increasing the return on R&D. For instance, if the good or service produced by a sector is complementary to the ICT, the more the ICT are performant, the higher the demand for the ICT and, therefore, also for the complementary good or service. Thus, consequently, the more the incentive to invest in R&D is high<sup>101</sup> (such as Hardware and Software).

Here we investigated on ICT as a source of knowledge externalities and we will pay particular attention to ICT as “research tools” in a broad sense, as well as on complementarities with other inputs in the third part of this thesis. Before dealing with the issue of ubiquity and strategic complementarity, we will return to the issue of measurement in the next chapter, which is essential in the case of a rapid technological change.

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<sup>101</sup>R&D is demand driven in this case

## 2.6 Appendices

### 2.6.1 Patent statistics

Patent statistics provide very useful data on research output covering many geographical areas as well as many technological fields. Indeed, as Schmookler remarked in 1966, in his book *Invention and Economic Growth* [198], patent data can be very helpful as a measure of innovative activity because it conveys information on the output and processes of inventive activity. Then, other authors followed him in using patent data on a large scale for economic research (Scherer, 1982 [195]; Grilliches and Lichtenberg 1984, [102]). However, the use of patent data requires a lot of caution. Many articles deal with this issue, among them we can cite Schankerman and Pakes (1986 [194]); Grilliches (1990 [101]); Harhoff et al. (1999 [115]) or else Jaffe et al. (2005 [127]). So we will not treat the issue again here but we shall mention the main bias that we must consider and the problems we face when we deal with the ICT field.

#### 2.6.1.1 PATSTAT

The PATSTAT database is a worldwide patent statistical database developed by the European Patent Office (EPO). It contains more than 20 tables with bibliographic data, citations and family links with about 70 million applications from more than 80 countries. This database is available without confidentiality restrictions since 2008.

The main interests of PATSTAT are that: (i) it provides harmonized data; (ii) it allows us resolve issues concerning family members and addressing problems, like applications from one applicant appearing under several different names; (iii) it contains related information on citations, procedural information and legal status

#### 2.6.1.2 Office-country bias

Many difficulties appear when we use patent data from different origins simultaneously. In particular, characteristics of patents, such as cost or procedures, differ between countries and patent offices.

There are two main consequences of these biases for our analysis:

1. The same number of patent applications does not match the same level of innovative activity in all countries;
2. The same number of citations for one patent does not match same level of innovation.



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**Differences in standards and procedures** The strict definition of the scope of an invention depends on the country, leading to different propensities in patents. In particular, for instance, in Japan, the unity of an invention covers a smaller area than in other countries so that an invention, which would be covered by a single patent in Europe, could result in ten patents in Japan. Dechezleprêtre et al. (2009 [70]) made an assessment of the differences between patent offices in terms of the number of patents per invention, defining a patent breadth coefficient for the different geographic areas. Some of their results is presented in table 2.5. They find that on average “seven Japanese patents result in approximately five European patents when filed at the EPO” so that the Japanese patent breadth is equal to 0.72 if the breadth of EPO is normalized to one.

Table 2.5: Patent breadth coefficient

Country/Office Breadth Coef.	Germany	Italy	EPO	France	USA	UK	Japan
	1.15	1.08	1	0.99	0.97	0.94	0.72

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*Source: Dechezleprêtre et al., 2009 [70]*

Furthermore, procedural changes may take place in a patent office, such changes can lead to ruptures in data that must be taken into account. This is also likely to happen at the EPO with the European Agreement on a joint patent for all European countries (agreement reached June 29, 2012).

When we proceed to make international comparisons based on patent statistics, we must take this bias into account and this assessment is necessary to correct data for geographical comparison. For this we use patent families, which group together patents that cover a single invention, instead of individual patents.

**The number of citations per patent** There is another bias between countries: the heterogeneity of the propensity to cite per patent. The average number of patents to which each patent refers (the number of backward citations) varies depending on the country. Once again, in order to proceed with a geographical comparison of the importance of the innovation based on patent citations (the more a patent is cited, the more it may protect a great invention), we must take into account this bias. Table 2.6 provides us with the average number of patent citations per application according to the office<sup>102</sup>. A further element disrupts analysis in this field: the propensity to cite varies as well over time. Whereas, in patents filed at the WIPO or at the EPO the number of citations per patent remains

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<sup>102</sup>One the main reasons for such differences in US compared to other regions is the “duty of candor” effect.

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relatively constant, in most national patent offices we observe an upward trend. The most important increase concerns the USPTO where this number has been multiplied by four<sup>103</sup>.

Table 2.6: Average number of patent citations per application

Office	USPTO	WIPO	EPO	INPI	IPO	DPMA
Nb. of Citations*	12.52	4.73	4.62	3.77	3.49	2.27

\*Calculated over the period 1978-2006

Source: Pillu (2009, [187]); calculations based on PATSTAT database

### 2.6.1.3 Patentability in ICT

**Equipment goods** Innovation in Office accounting and computing machinery as well as in ICT electrical goods represents almost the total patentable part of ICT innovations. This asymmetry is consequently observable in the citation distribution where these two sectors represent 99.97%<sup>104</sup> of the citations received (20.36% for Office accounting and computing machinery and 79.61% for ICT electrical goods). Therefore, indicators based on patent data are certainly more relevant in these sectors than in others where patentability is less obvious.

**Software and other ICT-related services** Concerning the patentability of software, the situation is relatively similar in USA, Japan and Europe, in the sense that it is not clear.

- In the European Patent Convention, article 52 excludes programs for computers “as such” from patentability. Nevertheless, if they are associated with a system producing a technical contribution, they could be patentable.
- In the United States where patent law excludes clearly “abstract ideas”, the classification of software as abstract ideas or not is mainly realized by case law.
- In Japan, software related inventions are patentable but must involve “a law of nature”, which means that they should be associated with hardware resources.

The main issue, to which patent offices have not yet found a completely satisfying answer, is about the definition of the framework of an invention involving an intangible product.

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<sup>103</sup> **Availability of the JPO patent citation data???** Concerning the JPO, citation data are not available after 1996 (this issue has been documented in the EPO document provided with the PATSTAT database, “European Patent OfficeWorld Wide Database Coverage Report January”, 2008).

<sup>104</sup> Our calculation based on our technology flow matrices built from PATSTAT and OECD concordance matrix

More generally, as a patentable invention should consist of a technical solution to a technical problem and must have an industrial application, innovations in service sectors are not relevant in this framework. Therefore, patent data cannot be used to study innovation in services sectors.

### 2.6.2 Technology flow matrices

#### General description

In our study, we use patent citation matrices, using the Johnson methodology (D. K. Johnson, 2002 [130]), that were constructed by H. Meijers and B. Verspagen in the framework of the DEMETER project and here we refer to their description of the matrix.

This matrix captures knowledge flows between sectors and between countries, and combines these two dimensions, i.e., it describes knowledge flows between a sector in one country and a possibly different sector in a possibly different country, whereas previous works had usually just addressed only one of these dimensions (between sectors within a country, or between countries).

The modeling and measurement challenge that this combination of dimensions provides was tackled by combining two ideas. The first one relates to patent citations, which represent a knowledge flow from the cited to the citing patent. The second idea is that of users and producers of knowledge. Both ideas had already been used in the analysis of knowledge flows, but their combination provides the perspective that is needed for the further analysis in our study. For the user-producer relationship, the work relied on the so-called Yale concordance matrix. This matrix is based on Canadian patent data, and it assigns, on the basis of the technology classification, a number of sectors that are the most likely origin of an invention, as well as a number of sectors that are the most likely users of an invention. By combining large amounts of individual inventions (patents), a statistical distribution (matrix) can be constructed in which “invention producing” sectors provide knowledge to “invention using” sectors.

This cannot be used to model knowledge flows between countries. Although one can identify the “invention producing” country by looking at the address of either the patent inventor(s) or the patent owner(s), the sectors of use of a particular patent are solely determined on the basis of the technology class in which the patent is assigned, and this does not contain any indication about the specific geographical location of the likely users. This is where information on patent citations is used. The patent citation identifies a specific citing and cited patent, and this contains information about the location of the inventor(s) and owner(s). Because there is a time lag between the cited and citing patent, a third dimension, time diffusion, could also be added to the analysis.

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The database used basic patent data from the PATSTAT database, which enabled the use of so-called patent families, i.e., groups of specific patents that cover a single invention. The resulting matrix is 3-dimensional, i.e., (cited sector within a country)-by-(citing sector within a country)-by time. This matrix can be used to weight RTD expenditures and identify direct and indirect RTD expenditure that result from this to productivity and other indicators of economic performance.

In particular, the spillover matrices are intended to deal with the two following points:

- R&D expenditure in a sector  $i$  in a country  $j$  have an effect on the efficiency of R&D in other sectors and/or in other countries. Similarly, the efficiency of R&D in sector  $i$  in country  $j$  is affected by R&D that is undertaken in other sectors and/or in other countries.
- R&D expenditures in sector  $i$  in country  $j$  are embodied in products (or services) produced in sector  $i$  in country  $j$ . These products are exported to other countries and may be used as inputs in other sectors. This may affect the productivity of these buying-sectors.

For the sake of clarity, through a misuse of language, we talk about patents that belong to a given IOM or SOU that cite other patents that belong to other IOM or SOU. However, firstly, patents refer more exactly to patent families, i.e. groups of specific patents that cover a single invention. So we will use the term patent as shortcut for patent family. Secondly, we directly allocate citations between IPC to citations between economic sectors. Thus patents do not appear as identified and indivisible identities in our matrices.

### Data

We only use patents for which the authority is USPTO, EPO or WIPO and which were filed in 1990 and later. But we select on patent authority only after having collected the information on citations to avoid throwing away citation to patents that are not filed at these 3 authorities. We do not use patents that are applied for in Japan since 29 million out of 37 million patents filed there do not have a country name.

### The concept of Industry Of Manufacturing (IOM) and Sector Of Use (SOU)

Between 1972 and 1995, the Canadian Intellectual Patent Office simultaneously assigned IPC codes along with an industry of manufacture (IOM) and a sector of use (SOU) code to each of over 300000 granted patents.

## CHAPTER 2. INNOVATION IN ICT INDUSTRIES

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Then, from the information provided by this database, the Yale Technology Concordance (YTC) and later the OECD technology concordance (OTC) were developed to translate IPCs into industrial definitions based on Industry Of Manufacture (IOM) and Sector Of Use (SOU). The original YTC provided concordance between IPC codes and the Standard Industrial Classification (the 1980 SIC-E version) and OTC translated or concorded the same, so that the industries of manufacture and sectors of use are consistent with the international standard ISIC definitions.

Johnson provides a good example to illustrate this transformation:

“In the IPC of B05 (sprayers and atomisers), a cosmetics atomiser might have an IOM in the glass container industry or metal valve industry, while a pesticide sprayer might have an IOM in the chemical fertiliser or agricultural machinery industry. Sectors of use (SOUs) would also differ, with the cosmetics atomiser used in the personal hygiene or cosmetics sector, and the pesticide sprayer used in field crop sectors.”

### The distribution of patent citations in several countries and sectors

As explained in the general description, in our matrices, we represent the probability of citation flows between sectors that belong to either the industry of manufacture (IOM) or the sector of use (SOU) of the cited and the citing patents. As one patent may have many inventors, producers or users, one citation that connects two patents may result in many fractions of citations between several countries and sectors.

Here we provide an example of one citation by one patent (family) to another patent (family)<sup>105</sup>. This example is for the industry of manufacturing (IOM) but works similarly for the sector of use (SOU). Note that the original Yale/Johnson Concordance Tables use IOM-SOU combinations but we focus on patent citations and from that perspective the matrices are not from IOM to SOU but from IOM in one country/sector to an IOM in another country/sector and similarly for SOU's.

**Patent a** (the cited patent):

- Has two inventors coming from the Netherlands (NL) and Germany (DE);
- Is related to 3 IPC codes as IOM: IPC1, IPC2, IPC3
  - IPC1 refers to sector A with fraction 0.5 and to sector B with fraction 0.5

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<sup>105</sup>We use the term patent as shortcut for patent family as explained above

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- IPC2 refers to sector A only (with fraction 1)
- IPC3 refers to sector C only (with fraction 1)

**Patent b** (the citing patent):

- Has three inventors, two coming from Germany (DE) and one from France (FR);
- Is related to 2 IPC codes as IOM: IPC3 and IPC4
  - IPC3 refers to sector C only (with fraction 1)
  - IPC4 refers to sector B with fraction 0.5 and to sector D with fraction 0.5

One single citation counts for one spillover, which means that this has to be spread over the sectors and countries for both the cited and citing patent. In the example we have 2 countries \* 3 ipc as cited and 3 countries \* 2 ipc as citing relations so each counts for 1/36th.

The resulting spillover matrix is (only the relevant countries/sectors are shown):

Table 2.7: Example of the distribution of one patent citation

		Citing Country/Sector									
		NL-A	NL-B	NL-C	DE-A	DE-B	DE-C	DE-D	FR-B	FR-C	FR-D
Cited Country/Sector	NL-A	0	0	0	0	0.04	0.08	0.04	0.02	0.04	0.02
	NL-B	0	0	0	0	0.01	0.03	0.01	0.01	0.01	0.01
	NL-C	0	0	0	0	0.03	0.06	0.03	0.01	0.03	0.01
	DE-A	0	0	0	0	0.04	0.08	0.04	0.02	0.04	0.02
	DE-B	0	0	0	0	0.01	0.03	0.01	0.01	0.01	0.01
	DE-C	0	0	0	0	0.03	0.06	0.03	0.01	0.03	0.01
	DE-D	0	0	0	0	0	0	0	0	0	0
	FR-B	0	0	0	0	0	0	0	0	0	0
	FR-C	0	0	0	0	0	0	0	0	0	0
	FR-D	0	0	0	0	0	0	0	0	0	0

The total sum of all elements is 1. The next cited-citing patent combination is added to this one and this is continued for all cited patents over one year (the patent filing date). This provides the spillover matrix from a specific year.

Furthermore, we use a time window of 5 years e.g. a patent filed in 1990 which is cited by patents filed in the period 1990-1994 will be used as relevant spillover but a citation coming from a patent filed in 1995 (or in 1989) will not be used.

CHAPTER 2. INNOVATION IN ICT INDUSTRIES

The final patent citation matrices

The resulting patent matrices have thus the following form, where  $Q_{qikj}$  is the number of citations of patents with IOM (or SOU)  $i$  in country  $q$  by a patent with IOM  $j$  in the country  $k$ ,  $P$  is the number of countries and  $N$  the number of sectors (size of the matrix for each year =  $(P*N)^2$ ):

Table 2.8: Final citation matrix

Year t		Citing Country-Sector													
	Countries	C <sub>1</sub>				...	C <sub>k</sub>				...	C <sub>p</sub>			
	Sectors	S <sub>1</sub>	...	S <sub>N</sub>	...	S <sub>1</sub>	...	S <sub>i</sub>	...	S <sub>N</sub>	...	S <sub>1</sub>	...	S <sub>N</sub>	
Cited Country-Sector	C <sub>1</sub>	S <sub>1</sub>					S <sub>1</sub>					S <sub>1</sub>			
		...													
		S <sub>N</sub>													
	...	...													
	C <sub>q</sub>	S <sub>1</sub>													
		...													
		S <sub>i</sub>							$Q_{qikj}$						
		...													
	...	...													
	C <sub>p</sub>	S <sub>1</sub>													
		...													
		S <sub>N</sub>													

### 2.6.3 An alternative generality index

Here we define an alternative generality index that takes into account the size of the citing sector in terms of total citation. Instead of looking at the distribution of citations received by the sector we consider at the distribution of the share of citations received by the sector in proportion to the total citations issued by each sector, to normalize the total citations issued by each sector to 1. In fact, this means that we suppose that each sector uses global knowledge on the same level and that the relative use of each type of knowledge is the same as that revealed by the proportion of citations.

The new index is thus define as:

$$\bar{G}_i = 1 - \sum_{j=1}^n \bar{c}_{ij}^2$$

where  $\bar{c}_{ij} = \frac{s_{ij}}{\sum_{v=1}^n s_{vj}}$  and  $s_{ij} = \frac{C_{ij}}{\sum_{v=1}^n C_{iv}}$ , with  $C_{ij}$  equals the number of citations issued by  $j$  and received by  $i$ .

We can illustrate the impact on the distribution of knowledge among sectors by comparing figures 2.11 with the previous figures 2.9. We see that the distribution is more balanced.

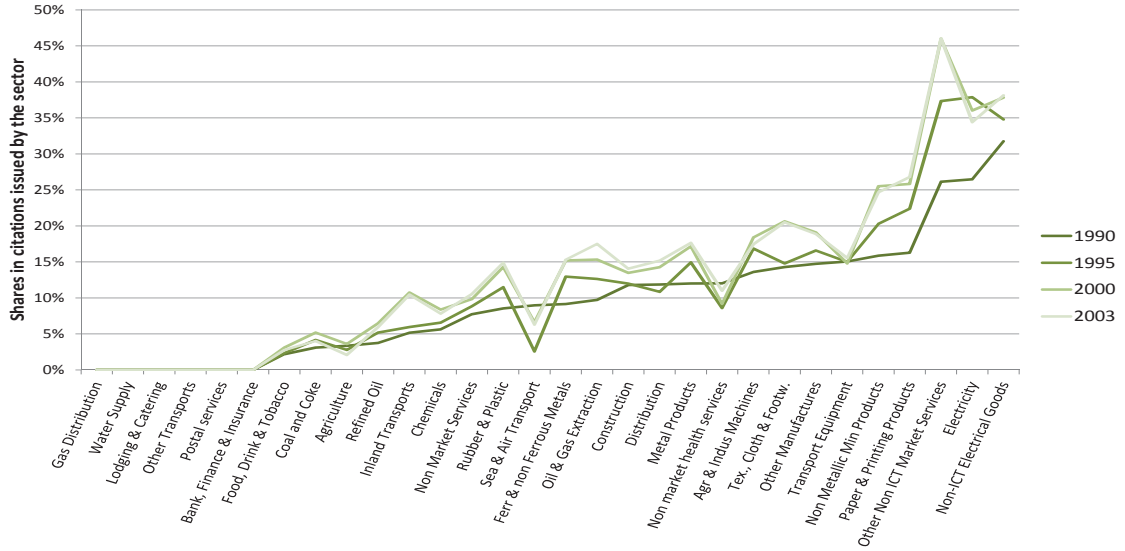
The results according to this generality index are given in table 2.9. We can see that there are very different from the previous ones and, especially, that the relative generality of the two ICT manufacturing sectors, which represent almost the totality of ICT patents, is improved. This change reflects the fact that ICT patents are relatively more often cited by sectors that make few citations than other sectors.



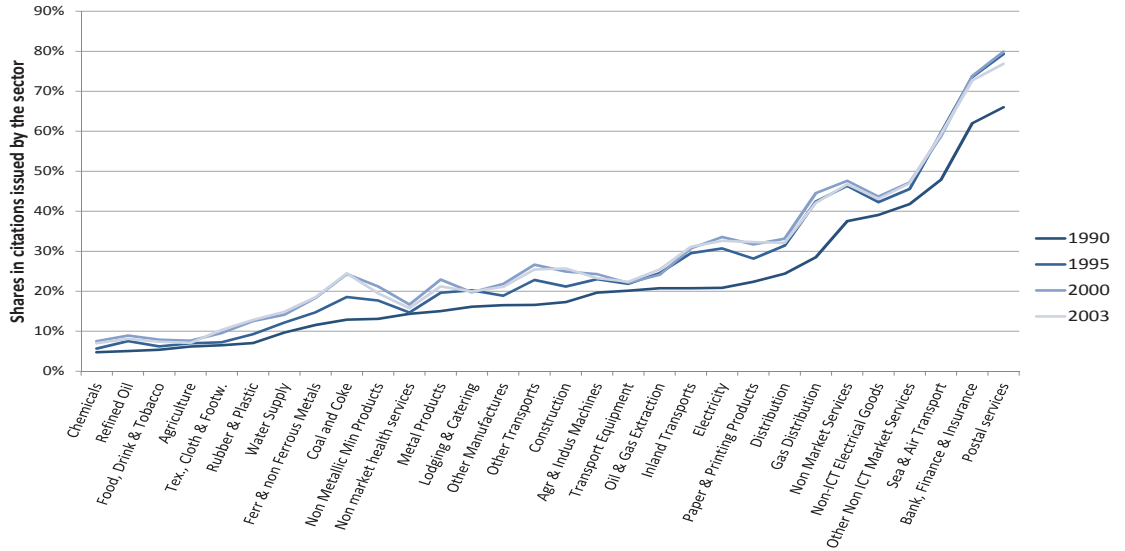
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Figure 2.11: Shares of ICT citations in total citations

(a) ICT cited industries and all citing sectors as IOM



(b) ICT cited industries as IOM and citing sectors as SOU



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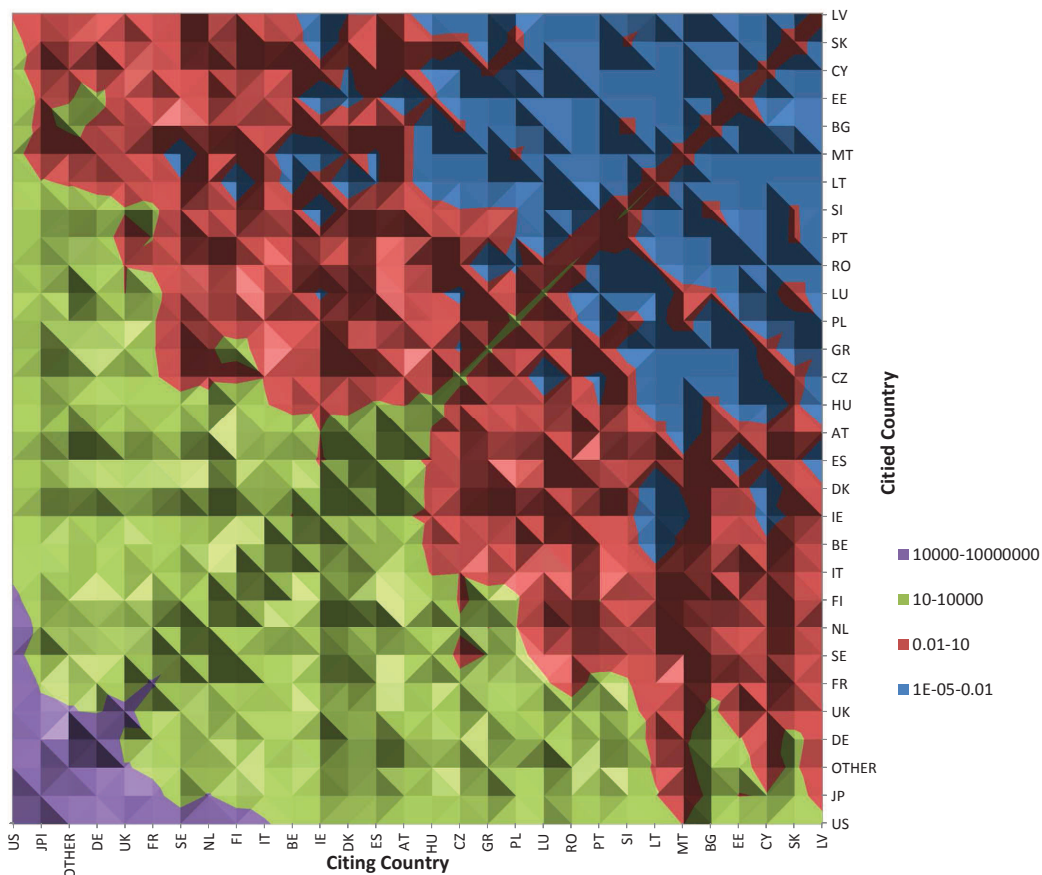
Table 2.9: Generality Herfindahl index

IOM-IOM		IOM-SOU		SOU-IOM		SOU-SOU	
Cited Sector	G	Cited Sector	G	Cited Sector	G	Cited Sector	G
Sea & Air Transport	0.03	Non Market Services	0.41	Non Market Services	0.46	Postal services	0.61
Non Market Services	0.07	Refined Oil	0.66	Sea & Air Transport	0.59	Gas Distribution	0.62
Distribution	0.19	Food, Drink & Tobacco	0.66	Oil & Gas Extraction	0.72	Refined Oil	0.66
Agriculture	0.30	Sea & Air Transport	0.69	Refined Oil	0.73	Oil & Gas Extraction	0.70
<b>Telecommunications</b>	<b>0.32</b>	Oil & Gas Extraction	0.73	Food, Drink & Tobacco	0.73	Ferr & non Ferrous Metals	0.71
Other Non ICT Market Services	0.32	Agriculture	0.75	<b>Telecommunications</b>	<b>0.76</b>	Lodging & Catering	0.71
Food, Drink & Tobacco	0.41	Coal and Coke	0.84	Ferr & non Ferrous Metals	0.80	Water Supply	0.77
Non market health services	0.45	Tex., Cloth & Footw.	0.85	<b>Office Machines</b>	<b>0.83</b>	Other Transports	0.78
Inland Transports	0.46	Ferr & non Ferrous Metals	0.85	<b>Computer Services</b>	<b>0.84</b>	Tex., Cloth & Footw.	0.79
<b>Computer Services</b>	<b>0.60</b>	Non Metallic Min Products	0.87	Coal and Coke	0.84	Coal and Coke	0.79
Refined Oil	0.63	<b>Telecommunications</b>	<b>0.87</b>	Non Metallic Min Products	0.85	Sea & Air Transport	0.80
Oil & Gas Extraction	0.63	<b>Computer Services</b>	<b>0.90</b>	Postal services	0.86	Agriculture	0.80
Construction	0.64	Electricity	0.90	Other Transports	0.86	Non Metallic Min Products	0.82
Ferr & non Ferrous Metals	0.65	Transport Equipment	0.90	Tex., Cloth & Footw.	0.86	Food, Drink & Tobacco	0.83
Coal and Coke	0.66	Other Non ICT Market Services	0.92	Agriculture	0.87	Bank, Finance & Insurance	0.85
Electricity	0.68	Non market health services	0.92	Transport Equipment	0.88	Non Market Services	0.87
Transport Equipment	0.83	Inland Transports	0.92	Paper & Printing Products	0.90	<b>Computer Services</b>	<b>0.88</b>
Tex., Cloth & Footw.	0.84	<b>Office Machines</b>	<b>0.93</b>	Electricity	0.90	<b>Telecommunications</b>	<b>0.89</b>
Paper & Printing Products	0.84	Construction	0.93	Other Manufactures	0.91	Paper & Printing Products	0.90
<b>Office Machines</b>	<b>0.85</b>	Chemicals	0.94	Bank, Finance & Insurance	0.91	Electricity	0.90
Non Metallic Min Products	0.86	Paper & Printing Products	0.94	Inland Transports	0.92	Inland Transports	0.90
Metal Products	0.91	Other Manufactures	0.94	Non market health services	0.92	Rubber & Plastic	0.91
Other Manufactures	0.92	Distribution	0.95	Construction	0.92	Other Manufactures	0.91
Chemicals	0.92	Metal Products	0.95	Lodging & Catering	0.93	Non market health services	0.92
Rubber & Plastic	0.93	<b>ICT Elec Goods</b>	<b>0.96</b>	Metal Products	0.93	<b>Office Machines</b>	<b>0.92</b>
<b>ICT Elec Goods</b>	<b>0.93</b>	Non-ICT Electrical Goods	0.96	Chemicals	0.93	Transport Equipment	0.92
Non-ICT Electrical Goods	0.94	Non-ICT Electrical Goods	0.96	<b>ICT Elec Goods</b>	<b>0.93</b>	Chemicals	0.93
Agr & Indus Machines	0.95	Agr & Indus Machines	0.96	Rubber & Plastic	0.93	Metal Products	0.94
Gas Distribution	--	Gas Distribution	--	Gas Distribution	0.93	Construction	0.94
Water Supply	--	Water Supply	--	Distribution	0.94	Distribution	0.95
Lodging & Catering	--	Lodging & Catering	--	Water Supply	0.94	Non-ICT Electrical Goods	0.95
Other Transports	--	Other Transports	--	Non-ICT Electrical Goods	0.94	<b>ICT Elec Goods</b>	<b>0.95</b>
Postal services	--	Postal services	--	Other Non ICT Market Services	0.94	Other Non ICT Market Services	0.96
Bank, Finance & Insurance	--	Bank, Finance & Insurance	--	Agr & Indus Machines	0.95	Agr & Indus Machines	0.96

Calculus based on knowledge matrix over the period 1990-2003

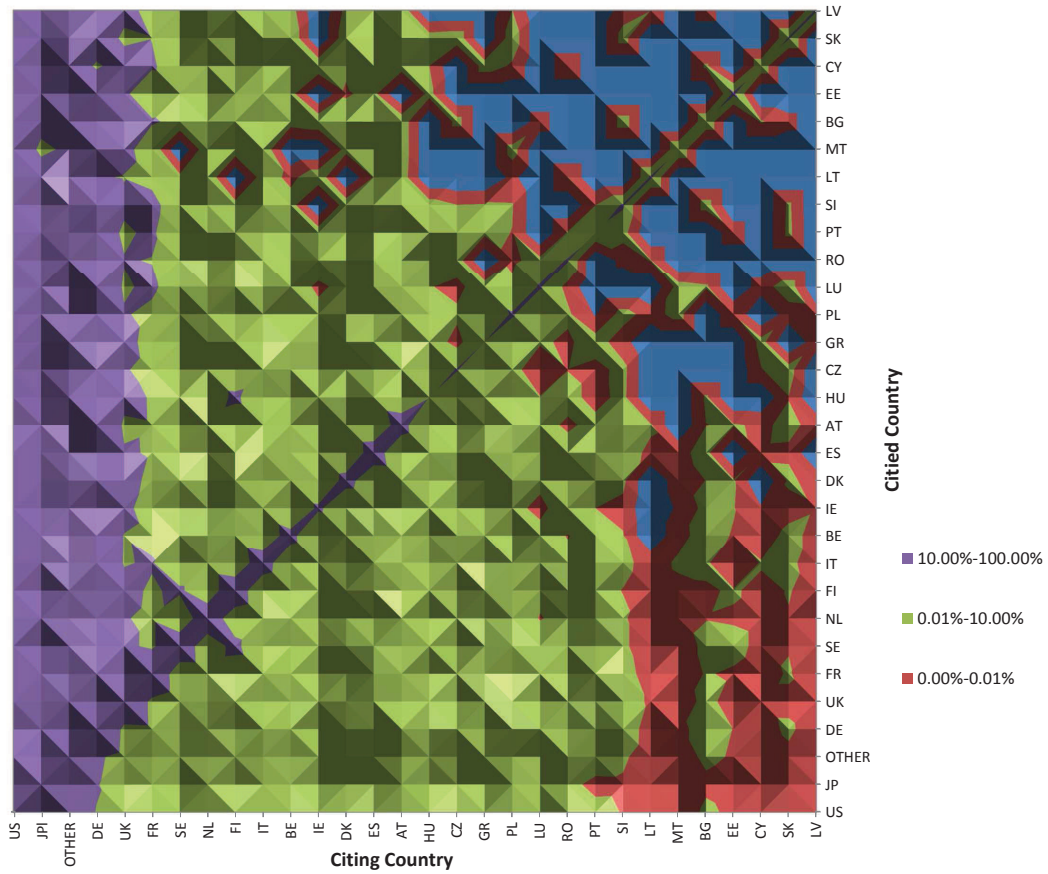
2.6.4 Citations between countries

Figure 2.12: Spillovers from ICT sectors to all sectors between countries between 1990-2003



Sources: PATSTAT, Johnson matrices

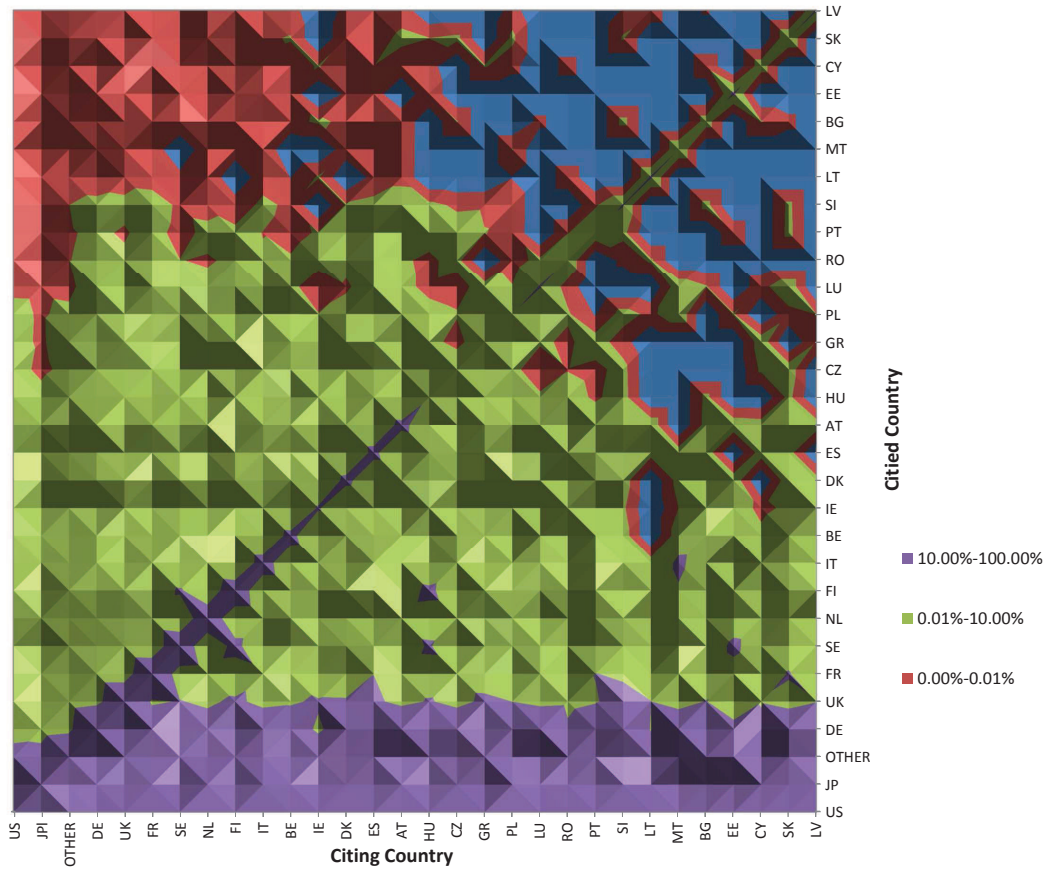
Figure 2.13: Destinations of ICT externalities\*



Sources: PATSTAT, Johnson matrices

\*in percentage of the total citations of the cited country between 1990-2003

Figure 2.14: Origins of ICT externalities\*



Sources: PATSTAT, Johnson matrices

\*in percentage of the total citations of the citing country between 1990-2003

## Chapter 3

# Measurement challenges

### 3.1 Introduction

In economics, the problem of measuring the volume of outputs and inputs arises repeatedly. If the nature of goods does not change, the volume-price separation causes no trouble as we only need a relative indicator of price. In other words, we need answer a question: What is the price of a car today compared to the price of that same car five years ago? How we can deduce the real variation in the volume of production over these five years from the difference of value of production? However, the economy does not only produce homogeneous goods and/or services. So the source of the problem is that goods, features of goods as well as the composition of aggregated goods change over time. Thus it is necessary to permanently adjust our measurements. Traditionally, these changes are continuous over time and relatively slow. In these circumstances, we can accurately anticipate and apply adjustment. The problem is more difficult to solve when changes in composition, in the nature or in the characteristics of goods are unpredictable and abrupt. These types of changes occur with the emergence of a new major technology that could be tangible, such as electricity or the computer, or intangible, such as organizational revolution. How many 1980's computers is a today's computer worth? How to measure the new services provided by internet?

These measurement problems are widely discussed, in the case of ICT, in Cette, Mairesse and Kocoglu (2000, [46]), Lequiller (2000, [149]), OECD (2002, [168]), Lequiller et al. (2003, [150]), Ahmad (2003, [5]) or Cette and Noyal (2003, [48]) and others. We summarize the main issues here. There are two important steps in the measurement of production or the use of one type of economic goods or

services. The first one is the identification and the insulation of the latter in the accounting system in value. In other words, what is the share in an economic transaction allocated to this type of goods or services. The second step, probably the most delicate, is the separation between price and volume in the total value. As we will see thereafter, this task is even more difficult to fulfil as the price and the composition of a good changes rapidly. In the case of ICT, the share of the three main components, which are computing equipment, communication equipment and software, has changed over the last three decades, as well as their respective prices because of the dazzling technical progress in the digital area. Thus, this problem of price measurement is particularly arduous to solve in ICT.

In the following subsection, we will show how ICT are included in data over time by the main national and international accountants. Then we will focus on the different methods used in order to separate price and volume. Finally, we will see how measurement errors, almost inevitable in such a context of rapid technological change, can impact the analysis and the diagnosis of economic performance, especially in a growth accounting framework. In particular, we will investigate if this may partly explain the productivity paradox described before.

### 3.2 Output/input measurement when a new technology occurs

As new technologies have a great influence on economic growth, the appearance and the diffusion of a technology as major as ICT should be considered in statistics. The awareness of the need for ICT measurement came gradually as they spread in the economy. Thus accountants take ICT in statistics increasingly into account. In this section, we discuss the way ICT are considered in statistics in terms of both output and inputs.

#### 3.2.1 Identification of ICT goods and industries

Of course, before measuring, we need to define what we want to measure. From this perspective, the different national and international statistical institutes established new classifications integrating the concept of ICT in order to provide analysts with the data they needed. Two main approaches were adopted: (i) the first is based principally on a technological point of view whereas (ii) the second is based on a functional approach. More precisely, the first one only considers the vectors of information and, thereby only considers sectors that produce the support of the information (the container) as ICT industries, while the second approach also includes information production sectors (the content) (see

## CHAPTER 3. MEASUREMENT CHALLENGES

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Coutinet, 2006 [60]). In this way, while the first approach defines “information technology industries”, the second depicts a larger “information sector”. Here we treat the two approaches more precisely.

**The container approach:** Historically, the United-States were the pioneers in ICT measurement in economic statistics and adopted this approach in its classification SIC 1987 which identified “information technology industries”. These industries include all producers and suppliers of this technology. Therefore, in addition to ICT producing industries, this classification includes computers and computer equipment and electronic measuring instruments wholesalers and retailers. It also includes communications equipment industries, software<sup>1</sup> and other computer related service industries.

At the international level, the inventory of ICT production comes from studies conducted by the OECD expert group WPIIS<sup>2</sup> inside the ICCP<sup>3</sup> committee in collaboration with Eurostat and the United Nation Statistical Commission. These studies led to a first international definition of ICT sectors in July 1998 based on the International Standard Industrial Classification Rev. 3 (ISIC Rev.3). This definition includes sectors that produce or supply ICT goods. It counts the manufacturing or service industries that fill the function of information processing and communication including storage, transmission and display by electronic means. Since this reshaping of the international classification, many statistical institutes, such as at European level or in France for instance, brought this definition in their classification<sup>4</sup>.

Several modifications were made to the original version. It was amended slightly in 2002 to reflect ISIC Rev. 3.1 changes in the Wholesale sector. In addition, in 2007, a revised definition of the ICT sector based on ISIC Rev. 4 was validated by OECD member countries (OECD, 2009 [170]). The list of ICT sectors according to this classification is given in box 3.1

**The container & content approach:** In a context of trade negotiations with WTO on opening the telecommunications market related to the vote of the “Telecommunications Agreement” in 1996, the American administration defined an “information sector”. This sector traces the outline of the industries that provide information based on ICT and not only industries supplying ICT equipment as

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<sup>1</sup>including only “prepackaged” software

<sup>2</sup>Working Party on Indicators for the Information Society, constituted in 1990

<sup>3</sup>Information, Computer and Communication Policy, created in 1982

<sup>4</sup>In the European as well as in the French accounting system, ICT sectors are made up of three main fields: computer - including production of computer and software - telecommunications and electronics.



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Table 3.1: OECD ICT sectors in the ISIC Rev.4

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<b>Manufacturing:</b>	
3000	Office, accounting and computing machinery
3130	Insulated wire and cable
3210	Electronic valves and tubes and other electronic components
3220	Television and radio transmitters and apparatus for line telephony and line telegraphy
3230	Television and radio receivers, sound or video recording or reproducing apparatus, and associated goods
3312	Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment
3313	Industrial process equipment
<b>Services:</b>	
5151	Wholesale of computers, computer peripheral equipment and software
5152	Wholesale of electronic and telecommunications parts and equipment
6420	Telecommunications
7123	Renting of office machinery and equipment (including computers)
72	Computer and related activities

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in the previous approach. Japan also defined an “Information and Telecommunication” sector in 2002. However, they distinguish the activities of ICT production and activities of information production more precisely. In particular, they distinguish, in the information activities, between those transmitted by electronic means and those transmitted by non-electronic means. In this way, the Japanese definition provides more detailed information than the American one.

Obviously, the interest of either of these approaches depends on the context and on the aim of the study. In our study we mainly use the first approach, insomuch as we are interested in the impact of the use of the (equipment) goods that support information, focusing on the technological aspect. Therefore, in our approach, we are led to distinguish the sectors producing these goods and the user sectors. In this context, *ICT producing sectors* will be defined here as sectors producing goods for processing and communication of information. While information production activities, like edition and publishing activities or radiodiffusion for instance, will be considered as *ICT users*. Nevertheless, the concept of the information container must be taken in a broad sense. This category is not limited to physical equipment or goods that allow the transmission and the treatment of information such as computers, telephone equipment but it also includes services that enable these equipments to fulfil their function. For example, these services include the distribution of these goods, the production of

operating systems or telecommunication services.

### 3.2.2 Identification of new collateral outputs and externalities

As described by some economists (Freeman and Soete [86] or David and Wright 1999, [68]), the emergence and the diffusion of a new technology reshape the economic structure. Such reshaping not only concerns the production process but also the nature of trade. As a consequence, the production of goods and services resulting from new technology is not always recorded by conventional statistics.

The difficulties encountered by statisticians have three main sources:

- The first is the impossibility to anticipate what are and how we will measure any new activities related to new technologies;
- The second is that new technologies could generate positive and negative externalities, which are inherently difficult to assess because they are outside markets;
- The third is that the financial counterpart or the benefits of these new activities may not correspond to the final service.

Let us return to these three difficulties more precisely and illustrate them.

**Anticipation of new technology related activities** Among the three mentioned difficulties, this is the one that relies the most on intuition. New services that appear thanks to new technology are not immediately taken into account. Indeed, at the beginning of adoption of a new technology, they remain unknown. If these activities are matched with financial counterpart, they appear in the macroeconomic output value but we cannot necessarily identify them as a result of this new technology. Furthermore, since the nature of these goods or services is ignored, it is difficult to know how to measure it. For instance the computerization of companies led to the development of counseling and training services. Should we account for expenditures on these services as intermediate consumption or as investment in the sense they are made in order to improve future production?<sup>5</sup>

Van Ark et al. (2003 [229]) also remarked that “compared to manufacturing, measurement problems concerning the change in output are much larger in many services industries. In several industries, such as the banking industry, it is very hard to accurately describe, let alone measure all the outputs

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<sup>5</sup>We will deal with this point in chapter 6 when we will discuss intangible investments.

### CHAPTER 3. MEASUREMENT CHALLENGES

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the industry provides. For example, [...] measurement problems in the financial securities industry have accumulated over the years. As Stiroh (2002 [214]) points out, output in financial services is measured simply in terms of the volume of trade and not as in other trade-related industries in terms of the margin between the purchase and sale of an asset. This may have led to an overstatement of productivity growth during the stock market boom of the late 1990s.”

**New technology related externalities** In addition, new activities or output related to new technology do not necessarily pass through markets. For example, as described in David (1989 [66], 1990 [67]) and David and Wright (1999, [68]), the wide diffusion of electricity has strongly reduced the risk of fire, and also improved the quality of lighting as well as of transport and has reduced maintenance requirements but this was not measured by the GDP. And even, it may have reduced the amount of fire insurance and therefore GDP.

Today ICTs also generate strong externalities that should be considered: they improve access to culture and enhance the availability of information.

These externalities are both positive and negative because of the double-edged nature of data access and harnessing. The power of these externalities is so great in both services that society sees the digital economy as, on one hand, a major source of future growth but, on the other hand, takes computer hacking<sup>6</sup> as well as the excesses of the use of personal data very seriously. This kind of apparent paradox reflects the difficulty of measuring the social and economic impact of such a major new technology in univocal way.

Technologies change lifestyles and this should be measured by governments<sup>7</sup>. If the production induced by the new technology is not captured by statistics the impact of the new technology on economic growth cannot be assessed.

Some externalities are structural and permanent but some others are temporal. Temporal externalities exist as long as a new business model is not found. The magnitude of this problem in trade evolution is reflected in the uneasiness of the cultural industry confronted with the expansion of freely available cultural contents, as shown by the controversies over the various legislation such as PIPA<sup>8</sup>

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<sup>6</sup>On a private and economic level, computer hacking is one of the biggest threats in industrial espionage and is presumed to occur widely. Since the cyber attack of Estonia in May 2007 following the relocation of the Bronze Soldier of Tallin, the notion of cyberwarfare emerged. In France, the publication of the “Livre blanc sur la défense et la sécurité nationale” on June 17<sup>th</sup> 2008, which considers the risk of a cyberattack against the country’s infrastructure as one of the most likely major threats in the next fifteen years, has led to creation of the “Agence Nationale de la Sécurité des Systèmes d’Information” (ANSSI).

<sup>7</sup>A first track could focus on the consumer surplus (see Brynjolfsson and Saunders, 2009 [40]).

<sup>8</sup>PROTECT IP Act (PIPA, long title : Preventing Real Online Threats to Economic Creativity and Theft of Intel-

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and SOPA<sup>9</sup> in US or the HADOPI<sup>10</sup> law in France<sup>11</sup>.

**Roundabout financial counterparts: a modern barter system?** Furthermore some new activities find their financial counterpart in a roundabout way. In fact, monetary consideration measured in statistics does not reflect the payment for the original service of the activity.

Internet allowed the proliferation of services such as online sales (e.g. eBay, Amazon, PriceMinister, etc.), search engines (e.g. Google, Yahoo), websites for listening to music on demand (e.g. Musicme, Deezer) or online encyclopedias (e.g. Wikipedia) or open source software (e.g. GNU licence) and freeware. Among these new services, many are completely free<sup>12</sup> and others are financed indirectly, for instance by advertising and not by the the final users (Facebook is not paid by its users but by sales of virtual goods, advertising and marketing). Furthermore, the explosive growth in capitalization of certain service companies suggests that this phenomenon is not negligible<sup>13</sup>. According to a McKinsey & IAB Europe study<sup>14</sup>, the value of online services financed by advertising and made freely available to Internet users in Europe and the United States is estimated at 100 billion euros. This number continues to grow steadily at a rate of 13% per year and should reach 190 billion euros in 2015.

The problem is that the financial counterparts do not necessarily correspond to the initial service. Actually, such indirect remuneration may hide a barter system.

Let us study the case of a free online service financed by advertising such as a website for listening to music on demand. Let us also assume that advertising decreases satisfaction for the use of this service (advertising between songs is unpleasant). In this case, the listener listens to his music for free but must endure the publicity pages. Or, in other words, the listener listens to his music for free in exchange for disagreeable advertising interruptions and the company, which advertises, pays for the music. Therefore this is a barter between the company and the auditor (music listening in exchange for time of attention for the brand). This phenomenon leads us to ask questions on how to evaluate

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lectual Property Act of 2011

<sup>9</sup>Stop Online Piracy Act

<sup>10</sup>Haute Autorité pour la Diffusion des Œuvres et la protection des droits sur Internet

<sup>11</sup>Three main business model could be contemplated for this purpose:

- a traditional one with a compensation proportional to the individual consumption;
- a lump sum (subscription or licence);
- a roundabout financial counterpart (advertising).

<sup>12</sup>Therefore they should be considered as externalities

<sup>13</sup>The Google's turnover was around 37.9 billion USD and advertising represents more than 96% of the revenue sources in 2011 (source: Google investor relations). Since its initial public offering in 2004, Google's valuation has increased from 27 to over \$ 200 billion today.

<sup>14</sup>McKinsey & IAB Europe, 2010 [158], study conducted with support from Google.

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this system. For this, McKinsey estimates that consumers' benefits provided by the free use of services sponsored by online advertising are three times larger than the revenues from online advertising<sup>15</sup>.

It is difficult to measure the real value of such services and what is the real increase in utility they provide. This leads to a misstatement of GDP as well as GDP growth. The inaccurate estimation of output, which could be more or less important depending on the technology, may be, at least in part, the cause of an apparent productivity paradox. Thus the questions raised are the following: (i) What is the extent of these unmeasured services? (ii) Will the structural change in the economy lead us to redefine markets or create new business-model for these services? (iii) And finally, will the monetization induced by these new business-model match real production?

**Two-sided markets and network externalities** We find theoretical explanations of such phenomenon in industrial economics based on two-sided markets, involving both theories on network externalities (initiated by Katz and Shapiro, 1985 [140] and Farrell and Saloner, 1985 [76] and 1986 [77]) and on multi-product pricing (famous examples are razor and blades or games console and games). Two-sided markets correspond to economic platforms having two distinct user groups that provide each other with network benefits. Rochet and Tirole (2006 [190]) explain that two-sided markets are considered “as markets in which one or several platforms enable interactions between end-users and try to get the two sides “on board” by appropriately charging each side”<sup>16</sup>. Furthermore, they add that this theoretical approach relies on the fact that “an end-user does not internalize the welfare impact of his use of the platform on other end-user.”

In fact, different situations of two-sided markets exist and we classify them as follows:

1. A single product generates two markets. For instance we can mention web search engines: the service consists of classifying web pages according to keywords and there are two types of end-users: those who want to easily find a relevant web page (constituted the first market) and those who expect to be easily found (second market). In this case the more things are well referenced the more the demand for the first market is high and, similarly, the more there are researchers using this platform the more the demand for being referenced in this platform is high.
2. The two-sided market is generated by two complementary goods. In that case, we distinguish two further situations:

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<sup>15</sup>See also McKinsey, 2011 [126].

<sup>16</sup>This definition can be applied more generally to multi-sided markets

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- (a) Consumers of both complementary goods are the same. We find example of such situation in phone and rental system charge. The network externalities are based on the fact that the utility of the phone and the rental system charge is increased by the number of phone holders and subscribers (another example may be “the killer applications<sup>17</sup>”).
- (b) Consumers of both complementary goods are different. An example is the Client-Server model where client programs (e.g. Internet Explorer or Firefox) and server programs (e.g. Internet Information Services or Apache) are two complementary goods and the utility of each one depend on the extent of the use of the other.

In addition, we can characterize network externalities depending on their origin, the markets on which they have influence as well as the nature of the relationship between end-users:

1. On one hand, we distinguish between membership externalities and usage externalities. These externalities are respectively linked with fixed fees (membership charges) and variable fees (usage charges). Membership externalities arise with “investment” decision (a standard has more utility if there is a great number of individuals that adopt this standard), whereas usage externalities arise from usage decision (I am able to call a friend on his phone if he subscribes, I can use my credit card if the merchant accept to pay a discount charge). Armstrong (2006 [8]) studies pure membership externalities, Rochet and Tirole (2003 [189]) study pure usage externalities and, as these two types of externalities are not exclusive in the sense that both types may exist at the same time, Rochet and Tirole (2006 [190]) combine both.
2. On the other hand, these externalities may be intranetwork externalities or Cross-market (inter-network) externalities (Gallaugher and Wang, 2002 [88]; Parker and Van Alstyne, 2005 [181]). There are intranetwork externalities when the extent of the consumption in one side of the market influences the demand for this same market side (Ex. of the social network: the more there are individuals registered in the network the more the network is attractive for new subscription); there is internetwork or Cross-market externalities when the extent of the consumption in one side of the market influence the demand for the other market side (Ex. of the Social network: the more there are individuals registered in the network the more the network is attractive for advertising).

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<sup>17</sup>A killer application is a computer program which needs a given technology and is so attractive or even necessary that consumers would buy the hardware technology just to run this application. one of the first example was VisiCalc and the Apple II, and we find also such cases in gaming consoles, etc.

3. Finally, we can also distinguish between cases with payment between end-users (such as in the case of credit card system where there is payment between the card holder and the merchant) and cases without payment between end-users (such as in the case of phone communications) (see Rochet and Tirole, 2006 [190])

These network externalities lead to the fact that firms are encouraged to provide both complementary goods. In particular, Windrum (2004 [237]) shows that “Microsoft’s linking of two product markets, the browser and the operating system, enabled it to exploit market power in one market in order to win a standards battle in the other”. Moreover, the “digital goods”, that are subjected to two-sided market, are also characterized by high fixed cost and low variable cost. This latter feature allows firms to adopt flexible price and a firm may even adopt negative prices in order to maximise its global profit (see Parker and Van Alstyne, 2005 [181]).

Therefore, these externalities may induce unobservable production in economic statistics. For instance, if a given firm chooses to provide a good freely to lock-in the market on the complementary good, economic data will only show the production of this complementary good for which end-users are paying a strictly positive price.

### 3.2.3 New technology as an input: the measure of ICT investment

Insomuch as we search to identify the economic impact of the use of ICT, we are especially interested by their use in production. In addition, to fully take into account the effects of ICT on production it is necessary to consider them as investments and not as intermediate consumption. Current expenditures in ICT are planned in order to increase future production. Therefore, they should be described as capital. In order to evaluate and analyse ICT contributions we need reliable measures of ICT investment and capital. As we will now see, ICT have not always been considered as such by accountants. In particular the accounting system differs according to ICT assets.

Traditionally ICT assets are broken down into three broad categories:

1. Computing equipment (IT<sup>18</sup>);
2. Software;
3. Communications equipment (CT<sup>19</sup>).

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<sup>18</sup>IT stands for Information Technologies.

<sup>19</sup>CT stands for Communication Technologies.

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In accounting systems, these assets have not been treated in the same way and the methods have changed over time. In particular, unlike spending in communications or computing equipment, software expenditure has not always been recognized as an investment. This is now the case in most OECD countries since the implementation of the System of National Accounts 1993 (SNA93). In the US (Grimm, Parker, 2000 [103]) as well as in France this change in software accounting practices dates from the end of the 1990's. Note that this accounting change had important implications since it increased GDP level by nearly 1.5% in the first year and growth rates of GDP by about 0.1 to 0.2 point per year in the United States (Cette, Mairesse and Kocoglu, 2000, [46]). In addition, accounting conventions for investment differ between countries (the definition of the minimum unit value to be considered as investment for instance) so that investments in software are somewhat underestimated in Europe and somewhat overestimated in US (Lequiller, 2000, [149]).

In spite of this improvement, several difficulties arose, including three major ones (see Cette et al. 2009 [47]):

- the availability and reliability of long time series;
- the breakdown between investment and intermediate consumption of total ICT expenditures;
- the measurement of (indirect) investment in custom software and the purchase of prepackaged software.

National accountants have adopted different solutions to these problems both between countries and over time. This is not without consequences on the homogeneity of the series, especially as there is no harmonization with the past. For example, the methodological change in measurement has induced a rise of 90% in the amount of software investment in 1999 in INSEE<sup>20</sup> statistics (from 11 billion Euros in the 1995-based national accounts to 21 billion Euros in the 2000-base, Cette et al. 2009 [47]) and a rise in the ratio of total software investment to GDP from 0.8% to 1.8% in 1999 in UK (Chamberlin et al. 2006 [49]).

Henceforth, in the state of the art of statistical methodology, ICT are counted in the following way by major accountants (such as OECD or Eurostat).

In national accounts, expenditure on ICT is seen as investment only if the product can be physically isolated. ICT embedded in equipment is not taken into account in ICT capital but in non-ICT capital.

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<sup>20</sup>Institut National de la Statistique et des Etudes Economiques (French National Institute for Statistics and Economic Studies)



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Therefore, the evaluation of ICT investment should be more precise in the service sectors than in industrial sectors, in which they are probably underestimated. Moreover, this measurement error is more important in computing equipment and software than in communications equipment, the former being more often integrated in production equipment as, for example in the CNC<sup>21</sup> machines. Thus, on the macroeconomic level, the more services are important in the economy, the more ICT expenditure is referenced as investment. At the sectoral level, if the share of communications equipment is small, ICT expenditure is more likely not to be referenced as investment (See Colechia and Shreyer, 2001 [52] and 2002 [53]). Whereas ICT are more often isolated physically isolated in finance services sectors for instance, they are more often embedded in producing capital in an automobile assembly line.

Software is particularly subject to important difficulties. On one hand, it is identified as such if it is not already embedded in hardware. For instance, operating systems are mainly included in computing systems which, consequently, are not pure hardware. On the other hand, softwares can be separated into three categories that are (i) prepackaged softwares, (ii) custom softwares and (iii) own-account softwares . When the first category is well identified (when software is not embedded in the IT), the two following are less accurately quantified since they are assessed indirectly. Custom software can be estimated using two different methods. The first one directly measures expenditure in software by firms using surveys. The second uses data on national production and importation of prepackaged softwares. The estimation of own-account software is based on the cost of the workforce allocated for developing software. However, the definition of software developers is different between countries and their compensation is difficult to evaluate. So software improvement expenses by companies are not really taken into account reliably.

Therefore, the identification of each component is not easy, especially for computing equipment and software On one hand, and the evaluation of the composition of ICT capital is influenced by the heterogeneity of the accuracy of measurement for each ICT category.

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<sup>21</sup>Computer Numerical Control

### 3.3 The separation between volume and price for ICT goods: the problem of the quality adjustment

The trade-off between volume and price in the value is undoubtedly one of the most important questions for the evaluation of the real impact of ICT on economic growth. Because of the speed of technical change, the choice between methods will have consequences on the measure of the performance of production. A good measure of production should reflect its potential utility. If the number of goods produced is constant but their quality increases, the total utility they provide also increases. Thus the volume of production measured should increase also. Underassessment of quality leads to an understatement of the real level of production and, by duality, to an overstatement of price. Therefore, if the improvement in quality is large, data overestimate the inflation rate. For this, the famous “Boskin report” (1996 [28]) evaluated the overstatement of the inflation rate at 1,1% point over the previous ten years in the United-States in 1996. According to the author, this overstatement was due to the four main sources of bias given in the table 3.2. Among these sources, “*new products and quality change*” represents more than half of the mismeasurement, which highlights the importance of the question.

In this part we describe how we can approach this problem, what the methods are, the difficulties and how different national accountants proceed in order to arbitrate between price and volume.

#### 3.3.1 Two main approaches can be used

For price assessment, the two following main approaches can be used:

1. The first one is the “*factor cost*” approach, which observes technical progress in production process.
2. The second one is the “*producer services*” approach, which considers the performance improvements in goods in production.

Usually, the latter method is used even if it is the most difficult to implement. Obviously the choice is not without consequences.

In order to illustrate the fact that the selected method is not neutral, we often use the example of the eraser in the literature. This example has already been widely described by many authors (Triplett, 1996 [221]; Cette et al., 2000, [46]...). Here we substitute the eraser with the processor to put the example into the context. In this demonstration, the processor is both an output for ICT producing

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Table 3.2: Estimates of biases in the CPI-Based measure of the cost of living

Sources of Bias	Estimate*
Upper Level Substitution	0.15
Lower Level Substitution	0.25
New Products/Quality Change	0.60
New Outlets	0.10
Total	1.10

\*in %point per annum

1. Substitution bias occurs because a fixed market basket fails to reflect the fact that consumers substitute relatively less for more expensive goods when relative prices change:
  - “First, BLS uses a fixed weight index based on the modified Laspeyres formula to combine price indexes for 207 items for 44 areas into a national CPI. The weights are derived from the Consumer Expenditure Survey (CES) and reflect surveys of individual households. We refer to the substitution bias at this level as Upper Level Substitution Bias. This bias is measured as the difference between the modified Laspeyres formula used by BLS and a Tornqvist index, which is (approximately) free of substitution bias. [...]
  - “The second type of substitution bias results from combining price observations for approximately 71,000 goods and services and information on prices for housing components of the CPI into indexes for the 207 items and 44 areas. We refer to the substitution bias at this level as Lower Level Substitution Bias.”

We can illustrate these two types of substitution as following: Upper level substitution: apple vs bananas; Lower level substitution: Golden Delicious apples vs. Jonathan apples

2. Quality change bias occurs when improvements in the quality of products, such as greater energy efficiency or less need for repair, are measured inaccurately or not at all. New product bias occurs when new products are not introduced in the market basket, or included only with a long lag.
3. Outlet substitution bias occurs when shifts to lower price outlets are not properly handled. (“The same VCR available for \$200 in a local appliance store may be only \$160 at a superstore. Since price data are collected within outlets, the shift of consumers to purchases from discounters does not show up in the CPI as a price decline even though consumers reveal by their purchases, measured by the steady shift in market share to discount outlets, that the price decline more than compensates for the potential loss of personal services” Gordon 2000 [90]).

Source: Boskin (1996 [28])

industries and an input for all industries. Let us look at examples of two types of innovation, a product innovation and a process innovation:

Product-Innovation: First, considering an innovation that permits the production, with the same quantity of factors, which means with the same cost as before, of a processor that is twice as fast. In the “factor cost” approach, the volume and the price of the processor will be unchanged but the global productivity of the using industries will increase. While, in the “producer services” approach, the volume is doubled, the price is divided by two and the productivity of using industries remains unchanged. Thus, according to the “factor cost” approach it attributes the productivity growth to the using industries while, according to the “producer services” approach, it attributes the productivity growth to ICT producing industries.

Process-Innovation: Now, let us consider an innovation that permits the production of the same pro-

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cessor as before (performance unchanged) but with half the factors. In the “factor cost” approach, the processor volume is divided by two, the processor price remains unchanged and the global productivity of the using industries will increase. While, in the “producer services” approach, the volume is unchanged, the price is divided by two and productivity remains unchanged. Therefore, in this case again, according to the “factor cost” approach we assign the productivity growth to the using industries whereas according to the “producer services” approach we assign the productivity growth to ICT producing industries.

Therefore both process and product (quality) innovations increase the total productivity of using industries in the “factor cost” approach, while they increase the total productivity of ICT industries in the “producer services” approach. Consequently, on macro-economic level, the selected method has no impact on the productivity measure only in the case of a domestic production and a domestic use of the processor. Indeed, assuming that all processors are produced abroad, following a “factor cost” approach, the improvement in processors will increase national productivity, while, according to a “producer services” approach, this technical progress will have no effect on national total productivity improvement (since it is included in the level of factor use).

In other words, keeping the case where processor are produced abroad, the “producer services” approach leads to measure exogenous technical progress in the processor producing countries but do not lead to measure any increase of the total productivity in our country. On the contrary, the “factor cost” approach leads allocating the processor technical progress in the processor user country. That is to say in an exogenous national technical change, whereas the innovation took place in the foreign country. By this way, using the “factor cost” approach, we not only explain less economic growth by attributing it to exogenous technical progress instead of attributing it to the increase in the ICT factor but in addition, we bias its measurement since we do not allocate it in the right place. Worse, we underestimate the economic growth of the producer country (or industry), since in the case of an ICT process innovation, which reduce ICT production cost, we diminish the volume of the ICT production in a “factor cost” approach and, in the case of an ICT product innovation (quality) we do not raise the ICT production volume.

Therefore, in our case, we prefer the “producer services” method because it attributes the output growth in the using sectors to the growth of inputs (measured in term of efficiency unit) since the technical progress is included in the input volume measure. By this way, the “producer services”

approach better identifies the origin of the output growth in ICT using industries<sup>22</sup>.

### 3.3.2 Approximations in the “producer services” approach

Using such approach, in an ideal world, price variations should reflect the variation of the value of each final efficiency unit perfectly. In the “producer services” approach, under the assumption of a perfect specification, the evolution of global productivity should be null in as much as the growth is completely explained by the evolution of the volume of factors that incorporates all the improvements in performance. The technical progress is attributed in its totality to the accumulation of inputs and there is no exogeneous and autonomous technical progress.<sup>23</sup> In the case of ICT, according to a “producer services” approach, “accurate price indices should be constant quality deflators that reflect price changes for a given performance of ICT investment goods” (Colecchia and Schreyer, 2001 [52]). However the complexity of the problem makes the “producer services” approach almost impossible to implement. Nevertheless, two alternative indirect methods have been developed to approximate it. The first one is called the *hedonic method* and the second one the *matched method*.

**The hedonic method** consists in estimating the value of goods with respect to their most important technical features (computing speed of processors, RAM, hard drive capacity...) with dummies for each period, geographic situation, etc. So, for a given price of one unit of goods, the efficiency unit price lowers with improvements in technical features. And the economic volume, mesured in efficiency, corresponding to one unit of the new good is greater than those corresponding to a unit of the old good. Furthermore, this method does not take into account the emergence of new features or the characteristics in terms of collateral cost<sup>24</sup>. So this method tends to overestimate price growth (or underestimate price decline) compared to a perfect “producer services” approach. Moreover, Cette et al. (2000, [46]) explained that in order to evaluate the factor productivity, this method is more suitable for assessing the willingness to pay for a certain volume than to measure the volume of production factor. This method is especially used to evaluate IT<sup>25</sup> price indices, in particular in USA since 1986<sup>26</sup>

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<sup>22</sup>Another advantage of this approach is that it allows the addition of stock from different generations

<sup>23</sup>In the case of the ICT, quality improvement leads to increasing labor productivity through a substitution effect between capital and labor but global productivity remains constant. On the contrary, in the “factor cost” approach, the growth of global productivity should be different from zero and should correspond to the difference between both measures of the global volume of factors.

<sup>24</sup>The case where the use of the new good diminishes associated variable costs is not taken into account.

<sup>25</sup>The component “computing equipment” of ICT capital as discussed above.

<sup>26</sup>With a backward projection until 1958.

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as well as in France and many European countries<sup>27</sup>.

**The matched method** consists in evaluating the variations between two successive periods in the price indices of goods alone<sup>28</sup>. Consequently, it does not take into account the price variations induced by the introduction of a new good. Thus, this method leads to underestimate price decline. This underestimation is all the more important as the arrival rate of new products is high, which is the case in ICT sectors.

Among methods that approximate the “producer services” approach, the use of the “matched method” underestimates the decline in investment price when there is strong technical progress like in ICT with respect to the hedonic method (Harhoff and Moch, 1997 [114]; Jorgenson and Stiroh, 2000 [137]).

**The methods differ according to the ICT category and the country** The methodology used to assess the price of the different ICT components is not identical. As previously explained, the most commonly used method for the evaluation of IT investment price is the hedonic one. Concerning software, several methods are used both within and between countries. For instance, in USA, accountants use both hedonic and matched methods for prepackaged software and they mainly used the “factor cost” approach for own-account software and a mean between the two previous methods for the custom softwares. France mostly uses a “factor cost” approach. Finally, for CT investment price indices, American offices use the hedonic method for only few CT goods (telephone swithing equipment) and a factor cost approach is used for the other CT goods. In France there is no special treatment for CT investment prices which are based on industrial sales price indices (that are close to the “factor cost” approach) and unit value indices for imported goods. Therefore, in light of these observations, the volume/price separation is all the more difficult to comprehend as the methods used are not the same for each ICT component and as these components are not strictly separable.

Now, from a dynamic point of view, if the weight of the factor measured using a particular method is modified, the evolution of global productivity will be influenced by the modification of the weight of each method. It will not only reflect real effects but also methodological changes. This remark is of interest here since, on one hand, ICT components are measured differently from other factors

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<sup>27</sup>We can note in addition that international accountants often correct data, for example applying the US indices, when national accounts do not take enough quality improvement into account in price indices.

<sup>28</sup>The good must exist in both periods.

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and even between them. On the other hand, both the weight in total capital and the composition of ICT have strongly changed over the past twenty years as we can see on figures 4.1, 4.2 and 4.4 in the next chapter. The graphic 4.1 shows that ICT investment represented less than 1.5% of GDP in the 1970's in all countries and reaches more than 2.5% of GDP in the 2000's with a peak at 4.7% of GDP in USA and UK. The figure 4.4 indicates that ICT capital, which represented only about 5% of total capital excluding residential infrastructure in volume during the 70's, henceforth represents between 20% to more than 50% of this total non residential infrastructure capital depending on the country. Furthermore the relative weight of each component also changes. Tables 4.1 and 4.2 show that the growth of the share of ICT in GDP is pulled up by IT and software. Differences in the deviation between the ICT composition in value and volume accross countries (for instance between US and France) that we observe on figures ?? and ?? in the appendix of this chapter leads us to have suspicious about the reliability of international comparisons.

The methodology heterogeneity does not have real justification, except for practical reasons. It is undoubtedly much more difficult to implement an hedonic method for software evaluation than for computer equipment, for which it is possible to determine physical characteristics, such as processor speed, memory capacity, etc. We can see in table 3.3, which is derived from the EU KLEMS database, that the price of IT decreases a lot in all countries while it is not the case for CT and software. It is therefore legitimate to ask whether these differences result from real deviations in technical progress among those assets or if they result from a heterogeneity in the price adjustment method.

The methodological note of the EU KLEMS database (Timmer and al., 2007 [216]) recalled the problem in software price adjustment with respect to IT: "...it is also clear that there remains much to be done before software statistics can said to be truly comparable. Much has been achieved in the last years but serious differences in the definitions still remain. An important issue is the estimation of own-account software and improving this should have a high priority."

Colecchia and Schreyer (2002, [53]) points out also that prepackaged software embedded in computing equipment are not recognized as software but as IT in the national accounts. This tends to underevaluate software and overevaluate IT on one hand and, on the other hand it tends to overestimate the volume of ICT as the IT component is more adjusted for quality improvement than the software component.

Finally, the hedonic method applied to IT goods and not to other goods may tend to attribute a too important contribution in global productivity gains to the IT producers with respect to the ICT

users (Brynjolfsson and Hitt, 2000 [38]).

**Complementarities of inputs and innovations** In addition, we can certainly assume that the software price is less adjusted for quality than it should be in a “producer services”, in particular because of the strong complementarity between softwares and computing equipment, both in terms of use and of innovation. We cannot use software without computing equipment, as well as we cannot use computer equipment without software. Then, even if technical progress is supposed to be weaker in software than in IT, the software’s utility depends on the use and on the technological level of computing equipment, as described above, and vice versa. A good example of such innovation complementarity is the multi-core processor. The improvement in performance gained by the use of a multi-core processor depends completely on the software’s capability to manage it (with the improvement of algorithms used). In particular, possible gains are limited by the fraction of the software that can be parallelized to run on multiple cores simultaneously; this effect is described by Amdahl’s law (Amdahl, 1967 [7]). A better approach could consider innovations and use of both software and hardware simultaneously in order to assess the price of one efficiency unit generated by these assets. We will adopt this approach at the macroeconomic level in chapter 8. For that purpose we will measure an intermediate asset produced by several factors and we will assess the complementarity between these factors.

### 3.3.3 Methodology in European databases

Here we focus on a database that we use in this study and which is certainly the most detailed database concerning European countries that includes ICT capital.

The EU KLEMS database provides harmonised measures for ICT investment at a detailed industry level for European Union member states<sup>29</sup> from 1980 to 2007<sup>30</sup> (see Van Ark, O’Mhony, Timmer, 2008 [230] for a complete description of the database).

EU KLEMS reports different prices for each ICT asset according to the country but assumes that quality adjustment in all countries is comparable in spite of the differences in selected methodology<sup>31</sup>. Therefore, the differences in aggregate prices of ICT between countries depend both on the differences in component prices and on the ICT composition.

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<sup>29</sup>It also provides harmonised data for United States, Japan and Australia

<sup>30</sup>The availability of the data depends however on the country

<sup>31</sup>However, EU KLEMS corrects data in countries without quality adjustment, mainly using US price indices.



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This methodological choice for harmonization is nevertheless not generalised across economic studies. Other authors (Cette et al., 2009 [47]; Colecchia and Schreyer, 2001 [52]) chose to adopt the same quality adjustment for all countries for the three ICT product categories. In this way they assume first that the prices of CT, IT and software are the same in all countries if the GDP price growth rates are the same. Second, they also suppose that the differences in the aggregate price of ICT between countries depends only on ICT composition and on the differences in the GDP price growth rates. The relevance of the method depends on the significance of differences between countries' methods.

Obviously, this has consequences. For instance, using the same quality adjustment for all countries Cete et al. (2009 [47]) find that, over the 1980-2005 period, the average annual decline in ICT prices was roughly 4.8% in US, 5.2% in UK, 5.7% in Japan and 4% in France. These price evolutions are quite different from those given by EU KLEMS since, over the same period, EU KLEMS obtains an average annual decline in ICT prices equal to around 4.5% in US, 2.4% in UK, 4.8% in Japan and an increase of 0.8% in France. Thus the relative ICT price decline is very different. We can ask the question of the legitimacy of such differences. Especially if the ICT price differences between countries in EU KLEMS reflects national accounting differences rather than real price differences. Colecchia and Schreyer (2001 [52]) remind us that "Wyckoff (1995) was one of the first to point out that the large differences that could be observed between computer price indices in OECD countries were likely much more a reflection of differences in statistical methodology than true differences in price changes. In particular, those countries that employ hedonic methods to construct ICT deflators tend to register a larger drop in ICT prices than countries that do not."

Table 3.3 shows the five year annual average growth rate of the ICT price as well as its components according to the EU KLEMS database for Germany, France, the Netherlands, the United Kingdom, Japan and the United States. EU KLEMS shows a similar downward trend in the ICT price with a permanent acceleration until 2000 and a slowdown after 2000. The most important drop occurs during the period 1995-2000. Furthermore, the decline of the aggregate ICT price is mainly due to the sharp drop in the computing equipment price as we can see on table 3.3.

National accountants are increasingly adopting the methods prescribed by the OECD and Eurostat Software Task Force (Cete et al. [47]). Thus, the measure becomes more and more homogenous across countries. Therefore, even if the oldest data may stay uneven because of the difficulties of backward projection, we can hope that national databases will become more comparable in the coming years.

## CHAPTER 3. MEASUREMENT CHALLENGES

Table 3.3: Annual average growth in ICT prices and in its components

		80-85	85-90	90-95	95-00	00-05	05-07
<b>Germany</b>	<i>Communication Equipment</i>				-2.1	-5.0	-4.5
	<i>Computing Equipment</i>				-15.2	-18.0	-21.6
	<i>Software</i>				-1.5	-2.0	-3.2
	<b>Total ICT</b>				<b>-8.6</b>	<b>-11.1</b>	<b>-16.8</b>
<b>France</b>	<i>Communication Equipment</i>	10.4	0.4	-1.6	-3.1	-1.7	-2.1
	<i>Computing Equipment</i>	3.9	-5.3	-6.9	-6.4	-7.3	-0.4
	<i>Software</i>	8.8	2.8	0.5	1.8	-0.3	1.1
	<b>Total ICT</b>	<b>8.9</b>	<b>1.0</b>	<b>-2.1</b>	<b>-1.4</b>	<b>-2.0</b>	<b>1.8</b>
<b>Netherland</b>	<i>Communication Equipment</i>	4.3	0.6	0.4	1.0	0.4	0.6
	<i>Computing Equipment</i>	-14.8	-9.9	-13.6	-21.6	-11.8	-8.1
	<i>Software</i>	-2.2	-3.0	-1.5	0.8	1.6	3.0
	<b>Total ICT</b>	<b>2.3</b>	<b>-3.3</b>	<b>-5.1</b>	<b>-10.6</b>	<b>-7.8</b>	<b>-4.4</b>
<b>United Kingdom</b>	<i>Communication Equipment</i>	-1.6	-4.7	3.2	-5.0	-4.8	-2.9
	<i>Computing Equipment</i>	-4.1	-16.0	-12.3	-18.3	-15.8	-6.9
	<i>Software</i>	13.8	6.8	7.1	1.0	1.6	2.3
	<b>Total ICT</b>	<b>10.4</b>	<b>-1.1</b>	<b>-0.2</b>	<b>-9.4</b>	<b>-10.3</b>	<b>-3.9</b>
<b>Japan</b>	<i>Communication Equipment</i>	-4.3	-2.8	-1.4	-8.8	-3.6	
	<i>Computing Equipment</i>	-13.8	-5.1	-5.6	-7.7	-18.2	
	<i>Software</i>	2.1	5.8	-1.2	1.3	-1.4	
	<b>Total ICT</b>	<b>-5.3</b>	<b>-1.6</b>	<b>-3.5</b>	<b>-5.2</b>	<b>-8.6</b>	
<b>United-States</b>	<i>Communication Equipment</i>	4.3	0.2	-1.2	-3.4	-3.4	-0.4
	<i>Computing Equipment</i>	-13.5	-10.9	-13.8	-23.0	-12.8	-12.1
	<i>Software</i>	0.4	-2.8	-2.8	-0.9	-1.2	0.7
	<b>Total ICT</b>	<b>4.1</b>	<b>-3.4</b>	<b>-4.8</b>	<b>-10.4</b>	<b>-7.1</b>	<b>-7.7</b>

Source: calculation based on EU KLEMS database

### 3.4 Summary

Here we summarize the main notions we discussed in this chapter. Our aim was to identify the main measurement difficulties that are inherent to the emergence of a new major technology such as ICT. Furthermore, we discussed both the way national accountants overcome these difficulties and, on the contrary, the limitations of current available data. Finally, we gave some indications in order to improve data in the future when it is possible.

This chapter identifies two main fields of measurement challenges:

- The first concerns the identification of outputs and inputs related to the new technology;
- The second concerns the trade-off between volume and price. The main challenge is that volume should reflect the real efficiency of an economic good.

Concerning the identification of output related to new technology, two tasks were identified.

### CHAPTER 3. MEASUREMENT CHALLENGES

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1. The identification of ICT producing industries and their output. For that purpose, two approaches were established to define ICT industries:
  - (a) The *container approach* which only considers the output of industries that produce the vector of information: ICT equipment. It defines *Information technology industries*;
  - (b) The *container and content approach* which adds the output of industries that provide information. It defines *Information sectors*.
  
2. The second task consists in the measurement of indirect output as well as externalities linked to the new technology. Three obstacles to accomplishing this task were described:
  - (a) The inability to anticipate the nature of indirect production;
  - (b) The absence of a market and externalities (Network externalities);
  - (c) New market organizations (e.g. roundabout compensations; two-sided markets).

Furthermore, in national accounts, only ICT investment are accounted. In addition, we have seen that ICT assets are accounted in ICT capital only if the products can be physically isolated and that ICT is broken down into three assets which are subject to heterogenous statistical treatment.

Concerning the trade-off between volume and price, two main approaches were outlined:

1. The “*Factor cost*” approach;
2. The “*Producer services*” approach.

The second approach goes better with our needs in the sense that it allows us to better identify the origin of output growth. However, its perfect implement is almost impossible. Today two approximative methods could be used: (i) the hedonic method and (ii) the matched method. In addition, the notion of complementarity of inputs and innovation challenges the evaluation of the price of inputs using only their own technological level. In such case, we recommend the definition of an intermediate input in order to assess “*producer services*” rendered by both complementary inputs grouped together.

Finally, we discussed heterogeneity in the selected methods depending on assets and countries. We saw how it may have an impact on our analysis.

### 3.5 Conclusion

In conclusion, measurement challenges are as many as they are complex. Here is a list of some key issues that is by no means exhaustive. The main source of the emergence and of the complexity of the challenge is the evolution of the “*techno-economic paradigm*” (Perez, 1983 [183], Freeman and Soete, 1997 [86]). As the nature of the economic activity evolves, the measurement problem changes. At each major change we must again ask what we need to measure and how to measure it but answering these two questions takes time. This is why, in the words of Nordhaus (1997 [167]), official data “miss the most important technological revolution in history”. Indeed we are witness to this deficiency in economic statistics today but it has also been the case before, as Nordhaus or David remind us, referring to the impact of lighting or electricity on economic statistics.

The time required for the adjustment of data has three main origins. The first is the time taken to theoretically understand the mechanisms related to the new techno-economic paradigm in order to identify the variables involved. The second is linked to the inherent difficulties concerning the nature of the new variables to measure. Indeed, these difficulties are different if the economic market reflects these variables, if we have to measure physical or intangible goods, if the technical features are clearly defined or not or, and even if the services of goods is also conditioned by complementary innovations. The third origin of delays in the provision of homogenous data is the ability of statistical organisms to coordinate themselves. Former solutions adopted by different statistical organisms are not always identical. For example, we have seen here that in the early 1990’s, ICT were not defined in the same way by all accountants or that software expenditure was not accounted as investment in all countries, even in the early 2000’s. Then, even after statisticians began to include the new economy, the period of homogenization persists. In addition, despite this statistical improvement, the oldest data remain incomplete because of the difficulty of backward projection of data.

During such periods of statistical adjustment, we can observe some parasitic phenomena that do not match reality. We have to disentangle the real phenomena and those due to measurement errors. In the computer age, the question is whether the productivity paradox is due to measurement problems or is real. We have seen in this section what the pathways through which measurement errors can bias the analysis are.

First, the development of the digital age was accompanied by the development of new goods and services that are difficult to identify and not reflected by the market. The non-inclusion of such goods and services in the measure of production has tended to underestimate GDP and then productivity.

### CHAPTER 3. MEASUREMENT CHALLENGES

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Second, the change in the way we consider ICT as an input, in other words taking into account of ICT expenditure as an investment rather than as intermediate consumption, also raised the level of GDP. These two first errors may have artificially generated a part of the Solow paradox in the early 1990's.

Third, the inaccurate quality adjustment of prices and volumes has also distorted the assessment of relative input contributions. In particular, the undervaluation of the quality of ICT induced an underestimation of production and of the productivity of ICT producers but also an overestimation of the multi-factor productivity (MFP) of ICT users. On one hand, if the entire quality improvement of a good is not taken into account, the measure of its production is underevaluated in term of efficiency units. On the other hand if the quality improvement of a factor is not taken into account, its use is also underestimated and then global productivity is overvaluated.

Fourth, sectoral asymmetry in terms of ICT composition and thus of the treatment of ICT investment could be improved. In fact, we saw that ICT are counted as such when they can be physically isolated. Therefore, in order to better understand the role of ICT as an input, especially in manufacturing industries, it should be relevant to include them also when other capital assets (like CNC machine, robot, etc.) are included.

Finally, the heterogeneity of measurements could be partly at the origin of differences in economic performance observed between countries. The countries that took into account the production of these new goods and services earlier show a higher productivity than the others. Likewise, if they apply a better adjustment for quality on ICT, the contribution of this input on economic growth will be higher than in the other countries. The question is, is the United States advance, with respect to other "western industrial economies" and especially with respect to Europe, in the production and the use of ICT a measurement effect or a real one.

After a descriptive analysis of ICT diffusion, the next chapter reviews some studies that assess ICT impact, mainly on US and European economies (and also on the Japanese one). We will see that, according to Colecchia and Schreyer (2001, [52]), the harmonisation of the price index between countries could have consequences in terms of output growth contribution, even though it seems not to have a significant impact on the relative gap between US and Europe. Moreover, both the Solow paradox observed in the early 1990's and the strong increase in ICT contribution to output growth after 1995 are not only artificial or due to mismeasurement, but are real.

## Part II

# ICT as an Ubiquitous Technology



## Chapter 4

# ICT diffusion and direct contribution on growth

### 4.1 Introduction

In this chapter in the first step we proceed with a descriptive analysis on ICT investment data. In particular, we describe the country and the sectoral specificities in the diffusion of ICT as input. We will see that an acceleration of ICT investment occurred between 1995 and 2000 and that the dotcom crisis reversed the trend but also that the magnitude of these variations depended on the country. This section also describes the dominance of computing equipment in ICT capital growth and finally highlight the sectoral heterogeneity in terms of ICT investment rate.

In the second step, we conduct a review of the literature that assesses the direct economic impact of ICT diffusion using a growth accounting framework. We will see that most authors identify three phases concerning ICT economic impact: a first phase during which only ICT producers benefit from their technical progress and even, that some other sectors (mainly services) are negatively impacted with symptoms of Baumol's disease. The second phase marks a "time to reap" ICT performance in most intensive ICT using industries and, finally, the dotcom crisis initiates a third phase, during which in the US labor productivity continues to grow despite of the drop of ICT investment, highlighting the need for more explanations than a simple ICT centered story.



## **4.2 The diffusion of the ICT**

In this section we simply observe and describe the gross data on investment in ICT, on ICT capital compensation, on ICT price and on the ICT composition at macro- and industrial-levels. We will also review some interpretations of the evolution of these variables given in the economic literature. In particular, we will mainly focus on six countries, the United States, Japan, United Kingdom, Germany, France and the Netherlands.

### **4.2.1 The evolution of ICT investment**

As we can see in figure 4.1, the global evolution of the ICT investment rate is quite similar across countries, with an increase until the beginning of the 1990s, followed by a temporal slowdown and, next, in the second half of the 1990s, by a boom-and-bust period, that is to say a strong rebound until the dotcom bubble burst in 2000 causing a fall, or even a collapse in several countries, in ICT investment.

After 1995, a period of euphoria began with frenetic investments in ICT industries without any link to profit. This euphoria accelerated until the stock market crash. Among the main causes that are often advanced to explain the general overvaluation of returns in the “dot-com” industries, we can mention the three following:

1. A change in market structure: the opening of a competitive market in the telecommunication industry in OECD countries during the second half of the 1990s.
2. An innovation effect: the strong decline in ICT prices and the popularization of the internet in the early 1990s.
3. A temporary demand effect: at the end of the period, the fear of the “Y2K bug” encouraged companies to invest in order to prevent the consequences of the bug (debugging, investment in backup systems, etc.).

The effect of each cause is hard to determine.

The relative magnitude of the boom-and-bust in the ICT investment rate is unequal between countries. For instance, the ICT investment boom is not as visible in Japanese statistics whereas it was particularly strong in the United States or in United Kingdom. This is to be compared with their respective economic circumstances, as Colecchia and Schreyer (2001, [52]) point out. In particular, the

## CHAPTER 4. ICT DIFFUSION AND DIRECT CONTRIBUTION ON GROWTH

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United States started their expansion phase in the early 1990s and Japan has been experiencing an economic downturn at the end of the 1990s. However, it is still remarkable that ICT investment “in spite of different positions in the business cycle [...] that all [...] countries under consideration witnessed a rapid increase of constant price ICT investment.” And it is noticeable that, in all countries, total investment was triggered by ICT investment.

Nevertheless, regarding these investment rates levels, countries are heterogeneous. Indeed, when the United States and the United Kingdom reached a maximum ICT investment rate of 4,7%, Germany did not exceed 2,8% and France, Japan and the Netherland were between 3,0% and 3,5% (table 4.1). The amplitude of the variations are also heterogeneous accross countries as we observed the United-Kingdom, the Netherlands and Japan catching up with the United-States during the 1980s, while France lagged behind. Only United-Kingdom managed to keep up with the ICT investment level of the leader. Moreover the bursting of the dotcom bubble had mmore effect on the most ICT intensive countries such as the U.S. and U.K. as they saw their ICT investment rate decline respectively by 1,3% and 1,4% between 2000 and 2005 while the fall was only 0,6% in France and Netherland and 0,8% in Germany and Japan.

In addition Van Ark et al. (2003 [229]) note that ICT investment accounted for more of the total investment in U.S. than in Europe, as it accounted for 17% of total business investment in Europe while it accounted almost for 30% in United States in 2000. Colecchia and Schreyer (2001, [52]) also highlight the stronger importance of ICT investment in US compared to other countries and they underline its role in US economic expansion: “The economic expansion in the United States in the 1990s was led by large and sustained growth in business investment, albeit from very low levels at the beginning of the decade. Remarkably, the rate of capital accumulation in the US business sector almost doubled in the second part of the decade, mainly because of strong investment in ICT capital.” Gordon (2004 [93] ou [94, 95]) puts the European gap into perspective and remarks that the diffusion of ICT is heterogeneous in Europe and is particularly weak in the *Olive belt* (Portugal, Spain, Italy and Greece). Then Gordon also suggests a comparison of contrasts within Europe and those within U.S.. For instance “Silicon Valley could be compared to Ireland and Finland, New England could be compared to Denmark and Sweden, and the midwestern heartland to France and Germany.” (Gordon, 2004 [94]) and he adds: “What stands out in this suggestion is the absence of any U. S. equivalent for the European *Olive belt* countries.” Thus, according to him, one reason for the discrepancy between Europe and U.S. in ICT adoption could be the existence of regions with very low levels of ICT adoption

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Table 4.1: ICT nominal investment and its components in percentage of GDP

		1970	1980	1985	1990	1995	2000	2005
<b>Germany</b>	<i>Communication Equipment</i>					0.6	0.7	0.4
	<i>Computing Equipment</i>					0.7	1.1	0.7
	<i>Software</i>					0.7	1.0	1.0
	<b>Total ICT</b>					<b>2.1</b>	<b>2.8</b>	<b>2.1</b>
<b>France</b>	<i>Communication Equipment</i>	0.5	0.4	0.5	0.5	0.5	0.5	0.4
	<i>Computing Equipment</i>	0.4	0.3	0.5	0.6	0.5	0.7	0.5
	<i>Software</i>	0.3	0.5	0.8	0.9	1.0	1.8	1.7
	<b>Total ICT</b>	<b>1.2</b>	<b>1.2</b>	<b>1.7</b>	<b>2.0</b>	<b>1.9</b>	<b>3.0</b>	<b>2.6</b>
<b>Netherland</b>	<i>Communication Equipment</i>	0.5	0.5	0.6	0.7	0.8	0.7	0.6
	<i>Computing Equipment</i>	0.3	0.5	0.9	1.1	1.0	1.1	1.0
	<i>Software</i>	0.1	0.3	0.6	0.9	0.8	1.6	1.5
	<b>Total ICT</b>	<b>0.9</b>	<b>1.3</b>	<b>2.0</b>	<b>2.7</b>	<b>2.6</b>	<b>3.5</b>	<b>3.1</b>
<b>United Kingdom</b>	<i>Communication Equipment</i>	0.2	0.3	0.4	0.4	0.7	1.1	0.5
	<i>Computing Equipment</i>	0.6	0.5	1.0	1.2	1.4	1.6	1.1
	<i>Software</i>	0.2	0.4	0.7	1.2	1.4	2.0	1.7
	<b>Total ICT</b>	<b>1.0</b>	<b>1.2</b>	<b>2.1</b>	<b>2.8</b>	<b>3.4</b>	<b>4.7</b>	<b>3.3</b>
<b>Japan</b>	<i>Communication Equipment</i>		0.6	0.5	0.7	0.7	0.8	0.5
	<i>Computing Equipment</i>		0.6	1.1	1.5	1.3	1.3	0.7
	<i>Software</i>		0.2	0.4	0.6	0.7	1.2	1.4
	<b>Total ICT</b>		<b>1.3</b>	<b>2.1</b>	<b>2.8</b>	<b>2.8</b>	<b>3.3</b>	<b>2.6</b>
<b>United States</b>	<i>Communication Equipment</i>		0.9	1.0	0.9	0.9	1.4	0.7
	<i>Computing Equipment</i>		0.5	0.9	0.8	1.0	1.1	0.7
	<i>Software</i>		0.4	0.7	1.1	1.3	2.2	2.0
	<b>Total ICT</b>		<b>1.9</b>	<b>2.6</b>	<b>2.7</b>	<b>3.3</b>	<b>4.7</b>	<b>3.4</b>

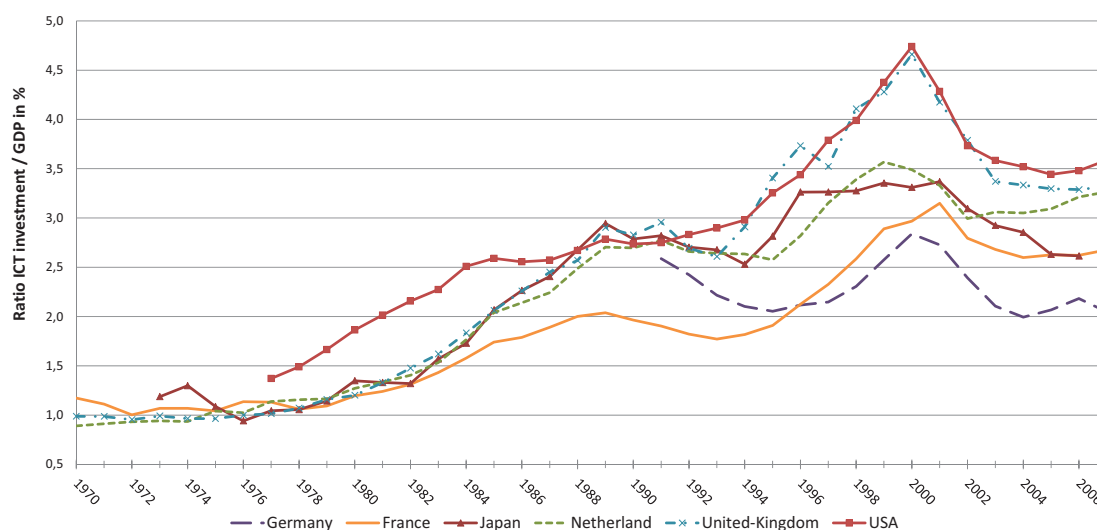
*Source: calculation based on EU KLEMS database*

in Europe but not in U.S.. However, it results from the literature that despite differences in national accounting systems, the gaps between U.S. and European countries such as France or Germany, seem to be real. Then, during the first half of the past decade, between 2000 and 2005, investment slackened off in all countries and we did not see countries with an ICT backwardness catching up the leader. Since 2005, ICT investment appeared to pick up again in most countries but this remains to be confirmed.

Furthermore, if we focus on the global evolution of ICT investment rates during the past thirty years, putting aside business cycles, we observe a strong upward trend. And moreover, regarding the ICT investment price in table 3.3, the trend is downward for all countries during this period except in France and in United-Kingdom where prices rose until the late 80s (however, this is perhaps due to measurement problems). This is also the case for ICT capital compensation per unit of ICT capital stock, figure 4.3, that stands for the cost of use of each ICT unit. So the acceleration of the growth rate of ICT investment could be partly explained by the strong decrease in its prices that has induced some substitution effects, especially with other capital assets and labor.

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Figure 4.1: ICT investment in percentage of GDP



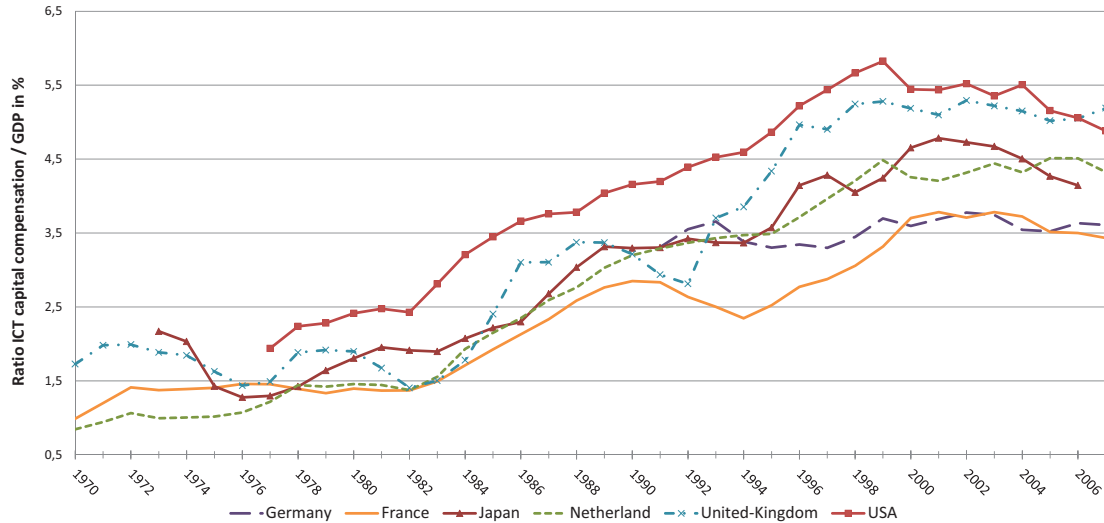
Source: based on EU KLEMS database

Table 4.2: ICT capital compensation and its components in percentage of GDP

		1970	1980	1985	1990	1995	2000	2005
<b>Germany</b>	<i>Communication Equipment</i>					1.2	1.1	1.2
	<i>Computing Equipment</i>					1.3	1.4	1.1
	<i>Software</i>					0.8	1.1	1.3
	<b>Total ICT</b>					<b>3.3</b>	<b>3.6</b>	<b>3.5</b>
<b>France</b>	<i>Communication Equipment</i>	0.3	0.5	0.6	0.8	0.7	0.9	0.7
	<i>Computing Equipment</i>	0.5	0.4	0.5	0.8	0.7	0.8	0.7
	<i>Software</i>	0.2	0.5	0.8	1.2	1.1	2.0	2.2
	<b>Total ICT</b>	<b>1.0</b>	<b>1.4</b>	<b>1.9</b>	<b>2.8</b>	<b>2.5</b>	<b>3.7</b>	<b>3.5</b>
<b>Netherland</b>	<i>Communication Equipment</i>	0.4	0.5	0.6	0.9	0.9	0.9	1.0
	<i>Computing Equipment</i>	0.3	0.6	1.0	1.3	1.5	1.7	1.4
	<i>Software</i>	0.1	0.3	0.5	1.0	1.1	1.7	2.1
	<b>Total ICT</b>	<b>0.8</b>	<b>1.5</b>	<b>2.2</b>	<b>3.2</b>	<b>3.5</b>	<b>4.3</b>	<b>4.5</b>
<b>United Kingdom</b>	<i>Communication Equipment</i>	0.3	0.4	0.6	0.5	0.3	0.8	0.7
	<i>Computing Equipment</i>	1.1	1.0	1.2	1.6	2.0	2.3	1.7
	<i>Software</i>	0.3	0.5	0.7	1.1	2.0	2.1	2.6
	<b>Total ICT</b>	<b>1.7</b>	<b>1.9</b>	<b>2.4</b>	<b>3.2</b>	<b>4.3</b>	<b>5.2</b>	<b>5.0</b>
<b>Japan</b>	<i>Communication Equipment</i>		0.7	0.6	0.8	0.9	1.3	0.9
	<i>Computing Equipment</i>		0.9	1.2	1.7	1.7	1.7	1.2
	<i>Software</i>		0.2	0.4	0.8	1.0	1.6	2.1
	<b>Total ICT</b>		<b>1.8</b>	<b>2.2</b>	<b>3.3</b>	<b>3.6</b>	<b>4.7</b>	<b>4.3</b>
<b>United States</b>	<i>Communication Equipment</i>		0.9	1.1	1.4	1.5	1.4	1.4
	<i>Computing Equipment</i>		0.9	1.5	1.3	1.6	1.8	1.2
	<i>Software</i>		0.6	0.9	1.5	1.8	2.3	2.6
	<b>Total ICT</b>		<b>2.4</b>	<b>3.4</b>	<b>4.2</b>	<b>4.9</b>	<b>5.4</b>	<b>5.2</b>

Source: calculation based on EU KLEMS database

Figure 4.2: ICT capital compensation in percentage of GDP



Source: based on EU KLEMS database

#### 4.2.2 ICT composition analysis

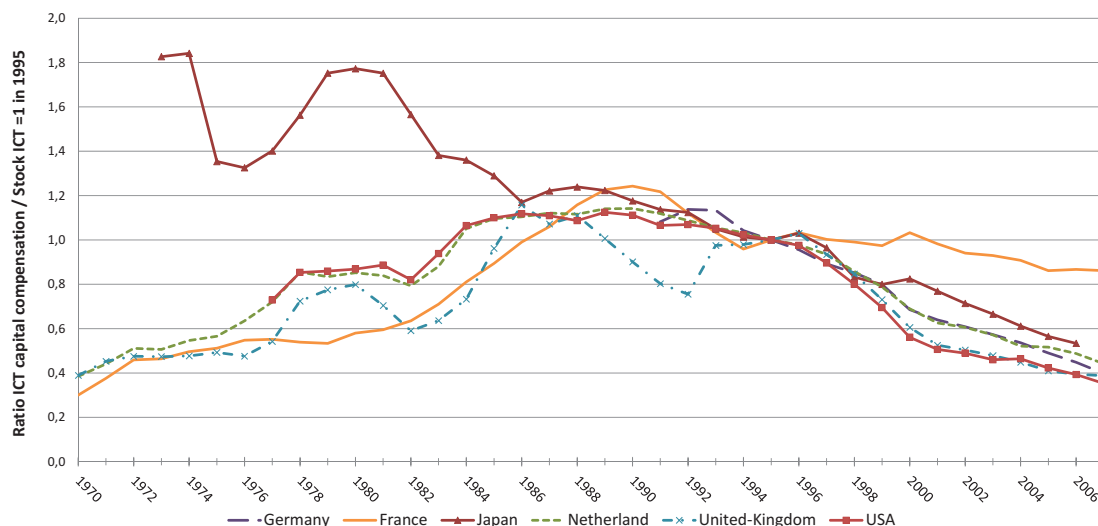
Figures 4.5 on page 155 a) (in appendix) give the evolution of the ICT investments according to EU KLEMS database. However, as the IT price decreases more than the prices of software or CT, the volume of the former should increase more than those of the others even if its weight in value remains constant. In the composition of ICT nominal investment, in most cases we can observe a decrease or a stagnation in the communication equipment share, an increase in the software share and a relative stagnation of the share of the IT component.

Moreover, figures ?? on page ??, in the same way, provide both the composition of ICT capital compensation, which could be taken as a proxy of the composition of ICT capital value.

Generally, as we saw on table 3.3 on page 119, the continuing decline in ICT investment prices is mainly driven by the decline of computing equipment prices, except in France and Japan where this decline is perceptibly lower. Moreover, in United States and the Netherlands it was supported in the 1980s by the sharp drop in software prices whose share increased in ICT investment. This explains their great difference from other countries during this period.<sup>1</sup>

<sup>1</sup>However, as we saw in chapter 3, we must be cautious when we compare the price evolution between countries. Indeed the high heterogeneity in ICT price evolutions, specifically in each ICT component, between countries is difficult to understand. We have to keep in mind that differences in the methodology could explain a part of these heterogeneities, despite of the preliminary homogenisation carried out by the authors of the EU KLEMS database.

Figure 4.3: ICT capital compensation per unit of ICT capital stock



Source: calculation based on EU KLEMS database

The strong decrease in IT asset prices explained both the decline of ICT investment prices and the volume growth in IT investment whereas the acceleration of software investment could be explained by the complementarity between software and computing equipment and momentarily by the fear of the “Y2K bug” (notwithstanding it is difficult to evaluate its magnitude) (Colecchia and Schreyer 2001, [52]).

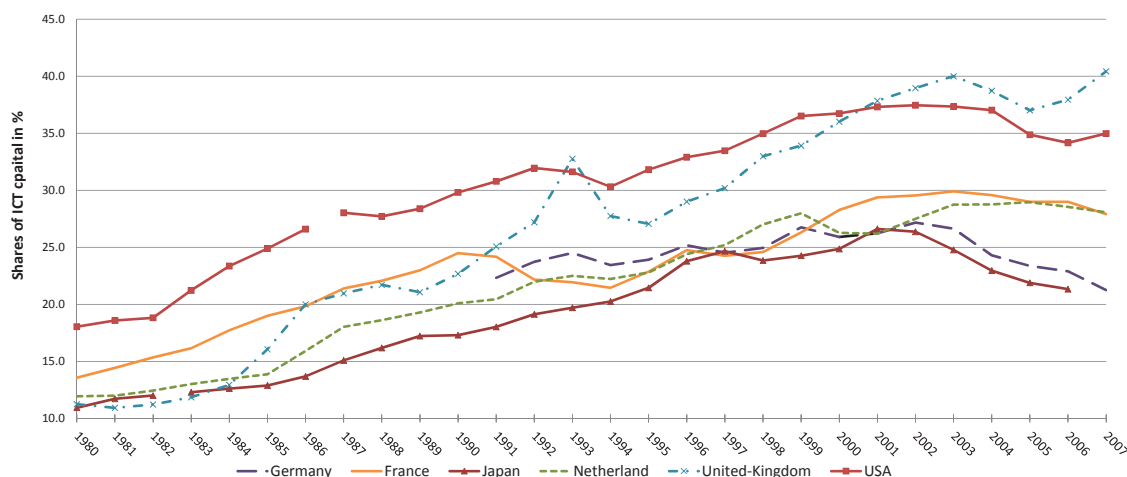
Finally, figure 4.4 shows a slowdown of the ICT capital compensation share in total capital compensation since 1999, which seems to be an inflection point of the ICT accumulation for most countries. We can also observe a stagnation of ICT capital per value added unit. This phenomenon has two main explanations. The first is obviously the decline in investment following the dotcom crisis. The second reason is the evolution of ICT capital composition. Indeed, the CT share of ICT capital stock tends to decrease in most countries relatively to the other ICT assets and this ICT component is the one with the lower depreciation rate. Thus, the global depreciation rate of aggregate ICT capital tends to increase and to contribute to the decline of ICT capital growth.

### 4.2.3 Industry-level approach

With respect to the total capital compensation (except residential and other constructions), service industries are obviously sectors where the share of ICT is the most important. In particular, if we exclude non-market services, *Financial intermediation* and *Post and telecommunication* are almost

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Figure 4.4: Shares of ICT capital compensation in Total capital compensation except residential and other constructions



Source: calculation based on EU KLEMS database

always the two sectors with the highest share of ICT in total capital and they are often followed by *Wholesale and retail trade* and *Real estate, renting and business services*. (See fig. 4.6 on page 158 in appendix).

Regarding ICT investment rates (see appendix figures 4.7 on page 161 which represent the 5 year average of nominal ICT investment in % of nominal value added for each sector<sup>2</sup>) the industries that are the most ICT intensive in most countries are *Transport, storage and communication*; *Finance, insurance, real estate and other business services*; *Electrical and optical equipment*; *Machinery NEC*<sup>3</sup>; *Transport equipment*; *Electricity, gas and water supply*.

The strong heterogeneity in ICT intensity between sectors led, in most studies, to the definition of three categories of industries: ICT producing industries which produce ICT equipment goods; ICT using industries which are the most ICT intensive industries (except ICT producers) and non-ICT industries that include the remaining industries. The frontiers between these three categories depend on the study and the sectoral aggregation level.

The industry-level approach has two interests. On one hand, it allows us to determine whether macro ICT intensity discrepancies are due to a sectoral composition effect or are due to a “within-

<sup>2</sup>On these figures we have excluded *Transport, storage and communication* because of its too high ICT investment rate and we have grouped together *Financial intermediation* and *Real estate, renting and business services*

<sup>3</sup>Non Elsewhere Classified

industry” effect. In other word, is the gap between the US and Europe due to a higher degree of specialization in the U.S. in ICT-intensive sectors or is it due to a higher ICT intensity in all sectors in the US? It is indeed a question that studies that we will describe try to answer and we will see in chapter 5 that the weight in GDP of ICT-intensive sectors is higher in the US than in Europe. On the other hand, this approach could also explain a part of the macro ICT composition. For instance, the increase of the weight of IT and software with respect to that of communication equipment in macro ICT investment could be explained by the higher development or an increase in ICT intensity in *Financial intermediation* with respect to the *Post and telecommunications* industry. Or, we can justify that the weight of software and IT in ICT investment is less important in Italy than in U.K. because the weight of the telecommunications sector in ICT investment relative to other ICT intensive sectors is more important in Italy than in U.K.. All in all, we cannot address the problem of the apparent lag of Europe behind the United States without considering geographical and sectoral heterogeneities.

### 4.3 The economic impact of ICT: a growth accounting framework

#### 4.3.1 Introduction

As we explained in the general introduction, the productivity gap between the United States and Europe has evolved irregularly during the last century. This gap could be partly explained by differences in the timing of business cycles, but not entirely. According to many of authors, the widening of the gap is often attributable to the slower emergence of the knowledge economy in Europe. In particular, Europe was slower than the United States in adopting electricity or the combustion engine at the beginning of the twentieth century and today in adopting ICT, as emphasized by Gordon (2004 [94]) or David and Wright (2003 [69]). Afterwards, European growth during the “war boom” was led by the increase in productivity in manufacturing industries reflecting scale economies and technical progress. However, later, the higher European labor productivity growth for the 1973-1995 period is more attributable to the accumulation of labor market rigidities than to access to superior technology or even faster innovation<sup>4</sup>. Then, the switch of western economies towards service activities slowed

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<sup>4</sup>In fact, we observe a sharp drop in the volume of hours worked in Europe compared to USA despite of the increase of the working people due to the “baby boom”. There is actually two reasons of this relative drop. The first reason is the sharp relative decline in employment rates, resulting from the rise of women and youth activity rates in the U.S.



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productivity growth in a first stage and, thus, the symptoms of Baumol's disease (see Baumol, 1967 [15] and Baumol and Bowen, 1968 [17]) that infected service activities appeared on macro-economic level and became a major challenge for western economies. At the same time, the technical progress in ICT provided a solution in United States where services became progressive sectors. Europe waited too long to adopt this solution and stopped to catching up with the U.S. between 1995-2006.

In the different studies based on growth accounting frameworks, as described by Cette, Kocoglu, Mairesse (2009 [47]), we observe the impact of ICT across two channels which are:

- “The substitution effect linked to the accumulation of ICT capital (capital deepening)”
- “The TFP gains, mainly driven by rapid technological progress in the ICT-producing industries”

Notwithstanding, the relative importance of these two effects strongly depends on the methodology used by accountants. As we have seen in chapter 3, this methodological choice is particularly essential in order to construct real ICT investment and stock series from nominal ICT investment. More precisely “the more the estimation of price changes take into account the improvements in ICT performance (through substantially upgraded products or new products), by relying in particular on hedonic methods, the larger is the contribution of capital deepening to productivity gains and the lower that of TFP, and conversely” as Cette et al. (2009 [47]) explained.

In addition, ICT impacts TFP in growth accounting analysis in two ways. A direct way, which is the consequence of the underestimation of the ICT quality in prices, and an indirect way, which is a consequence of the ability of ICT to create new innovation or organizational opportunities and lead to better performance. Thus, in view of this comment, we appreciate the importance of ICT price measurement. Indeed, the more the estimation of price changes takes quality into account, the more the contribution of capital deepening represents ICT direct impact and the more only indirect effects are attached to Multi-Factor Productivity (MFP<sup>5</sup>) gains. However, obviously, MFP gains do not only represent ICT impact but also non-ICT related impact such as innovations that have no links with ICT. Despite these potential measurement effects most of growth accounting analyzes are consistent.

In this section, firstly we recall the economic literature that describes the evolution of ICT contribution to output and labour productivity growth over time and across the sectoral structure of the economy. Secondly, we show how this economic literature try to comprehend the origins of the

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between 1963 and 1973 and, then, from the fall in the employment rate in Europe between 1973 and 1992. The second reason is the increase of the duration of paid leave in Europe. (see Gordon, 2004 [93])

<sup>5</sup>See box 4.3.1 for the explanation of the MFP

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differences between the United States and Europe focusing on a sectoral perspective in order to separate within-sector and between-sectors effects. In concrete terms, the question is to know if the US economic structure is changing under the cover of ICT industries or if Europe is worse than US at using ICT. Finally, after a checkup of the global contribution of ICT during the last decades, we will show why ICT analysis needs further elements.

### Box 4.3.1: Source of Growth Model

The growth accounting framework was pioneered by Solow (1957 [212]) and developed by Jorgenson and Griliches (1967 [132])

The aim of this approach is to decompose output growth into contribution of each input and productivity and, in this way, assess the relative importance of each production factor and the multi-factor productivity (MFP) (called the Solow residual, which is the portion non attributable to inputs). MFP either reflects technical progress or measurement errors and unmeasured output or input (such as R&D or intangible capital).

Growth accounting method (Colecchia and Schreyer, 2001 [52]):

Assuming a production function Cobb Douglas:

$$Y = F(A; L; K; T) = A.L^{\alpha_L}.K^{\alpha_K}.T^{\alpha_T} \quad (4.1)$$

with  $\alpha_L + \alpha_K + \alpha_T = 1$

Where  $Y$  is the value added,  $L$  is the labour,  $K$  the non ICT capital,  $T$  represents ICT capital and  $A$  stands for multifactor productivity.

We can log linearize and differentiate the function:

$$d \ln Y = d \ln A + \alpha_L d \ln L + \alpha_K d \ln K + \alpha_T d \ln T \quad (4.2)$$

The rate of change of output is presented as a weighted average of the growth rates of factor inputs, and of a multi-factor productivity (MFP) term  $A$ . The rate of MFP change is a Hicks-neutral shift of a production possibility function over time. The contribution of one input to output growth is evaluated by its cost or income share multiplied by its rate of volume change. In particular, the contribution of ICT capital to output growth is captured by  $[u^T T / PY] d \ln T$ , where  $u_T$  represents the user cost of a unit of ICT capital services.

Box 4.3.1: Source of Growth Model

In practice  $d \ln T$  is approximated by a logarithmic rate of change of ICT capital services:  $\Delta \ln T = \ln \left( \frac{T_t}{T_{t-1}} \right)$  and its share in the income by the following mean:  $\frac{1}{2} \left( \frac{u_t^T T_t}{P_t Y_t} + \frac{u_{t-1}^T T_{t-1}}{P_{t-1} Y_{t-1}} \right)$

We can also note that the rate of change of ICT capital input  $d \ln T$  is a weighted average of the rates of change of its three components: IT equipment, software, communications equipment:  $d \ln T = \sum_{i=CT,IT,Soft} \left[ \frac{u^i T^i}{\sum_i u^i T^i} \right] d \ln T^i$ . This is a Törnqvist index.

We can rearrange the equation 4.2:

$$d \ln Y - d \ln L = d \ln A + \alpha_K (d \ln K - d \ln L) + \alpha_T (d \ln T - d \ln L) \quad (4.3)$$

Then the growth rate of apparent labour productivity  $d \ln Y - d \ln L$  is a function of the variations in capital intensity (or capital deepening) in non ICT assets and in ICT assets and also of the increase in TFP.

### 4.3.2 The contribution of ICT: three stories

Many authors have used a growth accounting framework<sup>6</sup> in order to evaluate the contribution of ICT to output or productivity growth and most results are broadly consistent. In particular, they identify three periods with significant differences in terms of ICT impacts<sup>7</sup>.

The first period fits the first phase of widespread diffusion of ICT and covers the 1980s and the first half of the 1990s. Two remarkable facts characterize this period: the “productivity paradox” and the “Baumol’s disease” in service industries. The next period, which covers the second half of the 1990s, is the time for the paradox’s resolution and for healing of Baumol’s disease in the United States but not

<sup>6</sup>Van Ark and Inklaar (2005 [227] provide a literature review of growth accounting. However other studies have been made since and this review should be completed.

<sup>7</sup>We can mention:

- For the United States: Oliner and Sichel and Stiroh (2008 [174]); Oliner and Sichel (2000 [171] and 2002 [172]); Jorgenson, Ho and Stiroh (2003 [133], 2005 [134], 2006 [135], 2008 [136]); Jorgenson and Stiroh (2000 [137])
- For the Europe and Europe-U.S. comparison: Dimelis and Popaioanou (2010 [75]); Van Ark, O’Mahony, Timmer (2008 [230]; 2003 [228]; 2004 [224]); Van Ark and Piatkowski (2004, [231]); Daveri (2000 [64] et 2002 [65]).
- Or even: Cette, Kocoglu, Mairesse (2009 [47]) for France, United Kingdom, Japan and the United States; Colecchia and Schreyer (2001 [52]) at OECD countries level; Schreyer (2000 [200]) for the G7; Mairesse et al. (2000 [154]) for France; Oulton and Srinivasan (2005 [180]) and Oulton (2002 [179]) for the United Kingdom or Niinen (1999) for Finland.

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in Europe. Then productivity growth starts up again in US whereas Europe seems to have missed the train. Indeed, Van Ark et al. (2003 [229]) emphasized that productivity growth in the US accelerated from 1.1% in 1990-1995 to 2.5% per year in 1995-2000 whereas in Europe<sup>8</sup> it slowed from 1.9% in 1990-1995 to 1.4% per year in 1995-2000. Finally, after 2000 and the dotcom crisis, productivity continues to grow in US despite what was anticipated following the fall of ICT investment. In fact Oliner, Sichel, Stiroh (2008, [174]) according to published data, find that the annual average growth in labor productivity in the United States, which jumped from 1.5% between 1973 and 1995 to 2.5% between 1995 and 2000, rose little further to 2.8% during the last period until 2006. Thus the third period highlights the fact that ICT are not sufficient to explain productivity growth. In the following, we detail these three periods and we will see that the results of growth accounting models give different interpretations of the productivity growth depending on the period.

### Before 1995

From 1973 to 1995, the United States observed a long period of productivity stagnation with an average annual contribution to output growth of 1.5% point per year. This occurs despite of the wide diffusion of the computer which is yet supposed to be “a bicycle for our minds”<sup>9</sup>. This stylized fact led Solow to evoke a productivity paradox through his famous phrase mentioned in the introduction: “You can see the computer age everywhere but in the productivity statistics”. Nevertheless, in view of recent assessments, this assertion seems to be not totally true. Indeed, considering the estimations of Jorgenson et al. (2008 [136]) brought forward in the table 4.3 below, the level of the contribution to output growth attributed to information technology has more than doubled during the period 1973-1995 with respect to the previous period 1959-1973. But its contribution appears to be confined to ICT-producing sectors.

Furthermore, as ICTs are not yet sufficiently widespread, they are not yet a relevant factor to make comparisons between countries’ productivity. Indeed, Cette, Kocoglu, Mairesse (2009 [47]) show that, among the four countries in their sample, between 1980 and 1990, productivity growth is highest in Japan and France (resp. 3.1% and 2.9% per year in average) whereas it is lowest in United States (1.4%) (and 2.0% for United-Kingdom) and these differences come from both MFP and total capital deepening.

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<sup>8</sup>In Van Ark et al. (2003 [229]), Europe includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain and Sweden

<sup>9</sup>According to the phrase of Steve Jobs “What a computer is to me is the most remarkable tool that we have ever come up with. It’s the equivalent of a bicycle for our minds.” in *Memory and Imagination : New Pathways to the Library of Congress* (1991)

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Next, during the period 1990-1995, in France and in Japan, productivity growth declines because of a strong decrease in MFP contribution, the United States also see a slowdown in the productivity but a weaker one. Contrarily the United-Kingdom observes an increase in its productivity due to an increase in capital deepening (see table on page 149). Thus ICT does not appear as a major determinant of the productivity growth variation even if differences already exist in ICT contributions accross countries. Colecchia and Schreyer (2001, [52]), who study nine OECD countries, estimate that, over the period 1990-1995, the contribution of ICT to output growth in the business sector has been between 0.18 (in France) and 0.48 (in Australia) percentage points per year depending on the country. The United States is just behind Australia in their sample with an ICT contribution of 0.43 percentage points<sup>10</sup>.

This period is also the time of a disturbing problem that affects service industries, which have a growing part in employment. Indeed, Stiroh (1998 [213]) and Triplett (1999 [222]) observed that the productivity slowdown in U.S. occurs especially in services which are the most computing-using industries. This problem is known as “Baumol’s disease” and infects non progressive sectors. The effects of this disease result in an important inflation rate in these sectors because of the global increase in wages induced by technical progress in other sectors. This phenomenon is thus all the more worrying in that the computer is supposed to make these services progressive. It reinforces the idea of the productivity paradox linked to the ICT.

### 1995 - 2000

During the second half of the 1990s we observe an important rise of GDP both in Europe and in the United States. However, on table 4.4 we see that growth divergence, which was reinitiated in the early 1990s, is intensified after 1995 and that this divergence is mainly due to the contributions of labour, 1.53% against 0.88%, and ICT capital services, which was twice as important in US than in Europe, 1.16% against 0.59%. This US advantage “reflects the early start of many US enterprises in engaging [and in investing] in ICT [during the 80s]” (Dimelis and Popaioannou, 2010 [75]).

The comparison between nine OECD countries in Colecchia and Schreyer (2001 [52]) shows that over the period 1995-1999, the contribution of ICT to output growth jumped to a range from 0.33 to 0.86 percentage points (compared to a range from 0.18 to 0.48%points during 1990-1995). Even if the

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<sup>10</sup>Colecchia and Schreyer (2001, [52]) show that the harmonisation of the price index between countries has consequences in term of output growth contribution in a few countries. Globaly the use of an harmonised price index tends to increase the ICT contribution in Europe even though it seems to not have a significant impact on the existence of the gap between ICT contributions in the United States and the large European countries.

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Table 4.3: Sources of U.S. Output and Productivity Growth

	1959-2005	1959-1973	1973-1995	1995-2000	2000-2005
Private Output	3.58	4.18	3.08	4.77	2.93
Hours Worked	1.38	1.36	1.59	2.07	-0.16
Average Labor Productivity	2.2	2.82	1.49	2.7	3.09
Contribution of Capital Deepening	1.17	1.4	0.85	1.51	1.56
<i>Information Technology</i>	<i>0.43</i>	<i>0.21</i>	<i>0.4</i>	<i>1.01</i>	<i>0.63</i>
<i>Non-Information Technology</i>	<i>0.73</i>	<i>1.19</i>	<i>0.45</i>	<i>0.49</i>	<i>0.94</i>
Contribution of Labor Quality	0.27	0.28	0.25	0.19	0.36
Total Factor Productivity	0.77	1.14	0.39	1.00	1.17
<i>Information Technology</i>	<i>0.25</i>	<i>0.09</i>	<i>0.25</i>	<i>0.58</i>	<i>0.4</i>
<i>Non-Information Technology</i>	<i>0.52</i>	<i>1.05</i>	<i>0.14</i>	<i>0.42</i>	<i>0.77</i>
<b>Share Attributed to IT*</b>	<b>31%</b>	<b>11%</b>	<b>43%</b>	<b>59%</b>	<b>33%</b>

\*in % of Average Labor Productivity

Sources: Jorgenson, Ho and Stiroh (2008 [136])

level of their results is slightly different because of the use of an harmonised price index (see footnote 10), they also find that this contribution was highest in the United States than in the other countries. In addition they point out that software capital accumulation played an important role during the 1995-2000 period.

Furthermore, Van Ark, Inklaar and Guckin (2003 [228] [229]) spotlight that productivity growth in the United States accelerated from 1.1% in 1990-1995 to 2.5% per year in 1995-2000, whereas in Europe<sup>11</sup> it decelerated from 1.9% in 1990-1995 to 1.4% per year in 1995-2000 and that the European catching up process broke down. They also attribute this American superiority to more intensive investment in ICT assets and a better use of them in US and they show that “ICT contributes nearly twice as much to labour productivity growth in US as in the EU.”

Cette, Kocoglu, Mairesse (2009 [47]) observe, in the same manner, a rise in GDP in France and United Kingdom (but not in Japan) during this period. However they emphasize that whereas U.S. productivity rises by 1% there is a stagnation in France (the increase in MFP growth is offset by the slowdown in non-ICT capital deepening) and a deceleration of 0.5% per year in U.K. (because of a drop in non-ICT capital deepening and MFP growth). Moreover, they find a decrease in non-ICT capital contributions, especially in France, Japan and U.K., and a strong increase in ICT contributions for all four countries, highlighting the acceleration of the substitution effect between ICT and non-ICT

<sup>11</sup>In Van Ark et al. (2003 [229]), Europe includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain and Sweden

capital.

According to Oliner, Sichel, Stiroh (2008, [174]) for the United States, the first leap (of about 1% point) is mainly due to a greater use of ICT capital and faster MFP growth for ICT producers<sup>12</sup>. Thus ICT capital deepening and MFP growth, which accounted for more than the total speedup in labor productivity growth during 1995-2000, supply the largest contribution to productivity growth. These results are in line with other studies and confirm the central role played by ICT during the second half of the 1990s.

Gordon (2004 [94, 95]) attributes the differences between Europe and US to several factors and especially to the development of ICT-producing industries in US, entrepreneurship encouraged by public policies and synergy between public and private research and the financing of innovation.

In addition Van Ark, Inklaar and Guckin (2003 [229]) also highlight a strong acceleration in productivity growth in ICT using services in the US (this productivity growth jumped from 1,9% per year during the period 90-95 to 5,4% per year on average during the period 1995-2000) which is not followed by EU. Even though for both Europe and U.S., ICT producing and ICT using industries, and especially ICT using services, seem to have a faster productivity growth than the non-ICT industries. As these sectors account for more than a quarter of US GDP, the authors explain an important part of the aggregate growth. Moreover they show that, globally, ICT producing manufacturing and ICT using services together accounted for more than the total productivity growth difference between the EU and the US (respectively 0.48 and 0.89%points).

The estimations of Dimelis and Popaioanou confirm that the impact of ICT is more important in ICT producing and intensive using sectors both in US and in Europe. In US they show that “the ICT contribution was 100% higher in ICT producing and 25% higher in ICT using industries” and in Europe “the ICT contribution was 61% higher in ICT producing and 31% higher in ICT using industries (as compared to the remaining EU industries)”. These results corroborate those of Van Ark and O’Mahony (2003a [228]) “arguing that there is a strong potential to exploit growth benefits in the EU service industries that make intensive use of ICT” even though the ICT impact declined between 1990-1995 and 1995-2000 contrary to what was happening in US (Dimelis and Popaioanou, 2010 [75]).

So we can ask whether the difference in productivity growth between US and EU comes from a real difference in productivity growth inside sectors or if it comes from a relative change in the sectoral

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<sup>12</sup>The increase of MFP growth is especially large for producers of semiconductors that the authors take into account separately in their model

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structure of the economy. In other words, does the United States grow faster because the productivity of each or some important sectors<sup>13</sup> grows faster or because the United States becomes more specialized in industries with higher productivity growth with respect to Europe? For this purpose Van Ark et al. (2003a [228]) decompose the productivity growth differences in four components and explain the contribution of a given industry with:

- its own productivity growth;
- its employment share (in total employment);
- the variation of its employment share;
- the level of its productivity.

The combination of the two first components gives the “within-industry” effect, which represents the contribution of the productivity change of the considered sector to the global productivity change, whereas the combination of the last two gives the “between-industry” effect, which reflects the change in the sectoral structure of the economy<sup>14</sup>.

“The results show that US productivity has grown faster than in the EU because of the dual effects from a larger ICT producing sector and faster growth in services industries that make intensive use of ICT.” The three main industries that account for most of the U.S. advantage are wholesale and retail trade and the financial securities industries.

Despite a higher labour productivity growth in ICT producing manufacturing industries with respect to other industries in Europe<sup>15</sup>, United States keep a strong advance in these sectors. Indeed, according to Van Ark, Inklaar and Guckin (2003 [229]), for the period 1995-2000 productivity growth in ICT producing manufacturing sectors was 23.7% per year in average in the U.S. compared to 13.8% per year in EU.

In addition they show, on one hand, that the ICT using services contribution, which is the largest contribution to the overall productivity growth difference between EU and U.S., is mainly due to higher productivity growth rates in US. And only three sectors account for the entire contribution, namely

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<sup>13</sup>Especially of ICT using or producing industries.

<sup>14</sup>The weight of sectors in productivity being evaluated by their share in employment.

<sup>15</sup>This superiority of the ICT producing manufacturing industries in Europe could be partly due to price indices correction with the application of U.S. deflators for ICT products (based on hedonic price indices) for all countries that make no quality adjustments in Van Ark et al., 2003 [229]



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wholesale, retail trade and financial securities (together they account for 0,9 of the 1,1 percentage point growth differential between EU and U.S.).

On the other hand, they show that the ICT producing manufacturing contribution is due to differences in employment shares between Europe and United States. It means that these sectors contribute more to the overall productivity growth in US than in Europe because of their bigger weight in U.S.. This weight difference is also observable in term of GDP (it accounts for 2,6% of GDP in US against 1,6% of GDP in EU). More recently, Van Ark, OMahony, Timmer (2008 [230]) confirm that the ICT producing sector is bigger in US than in EU and that there is no great difference in productivity growth rates in ICT-producing industries<sup>16</sup> between EU and US. Thus the differences in the impact on aggregate growth of this sectors only comes from a composition effect.

The between-industry effects are relatively small on this time interval but we probably need more longer time series to highlight these effects. Moreover, the productivity level contribution inside the between-industry effect is negligible in most types of industries, this means that “the industry productivity levels relative to the aggregate productivity level are very comparable across Europe and the United States”.

### After 2000

**Expectations after the dotcom crisis** The early 2000s were marked by the burst of the dotcom bubble subsequent to disillusion on the ICT investment returns and the “Y2K” bug. In this context both ICT investment and GDP growth slow down in U.S. and Europe, as we can see on figure 4.1 and table 4.4 and most economists expected a slowdown in productivity growth. Indeed, on one hand, knowing that labour productivity growth is pro-cyclical, the boom between 1995-2000 could induce an overstatement of labour productivity during this period, especially in U.S. and, on the other hand, the identification of ICT as the major driver of the speedup in the second half of the 1990s has lead economists to anticipate a slowdown in productivity growth following the sharp pullback in ICT investment after the burst of the dotcom bubble in 2001. Even if some authors, considering other factors than just ICT investment such as innovation or human capital in their forecasts, anticipated a lower productivity growth potential in future years than during the late 1990s. Among them we can find Gordon (2003) who underlined the decreasing importance of new incremental innovation: the

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<sup>16</sup>Which do not include software industries.

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Table 4.4: Contribution to GDP growth

<b>EUROPE 15</b>	<b>1985-1990</b>	<b>1990-1995</b>	<b>1995-2000</b>	<b>2000-2005</b>	<b>2005-2007</b>
<i>Growth rate (annual average rates,%)</i>					
<b>GDP volume</b>	<b>3,21</b>	<b>1,64</b>	<b>2,62</b>	<b>1,56</b>	<b>2,85</b>
<i>Contribution to GDP growth (% points)</i>					
Hours worked	0,80	-0,49	0,71	0,31	0,89
Labour composition change	0,27	0,36	0,17	0,18	0,07
ICT capital services	0,40	0,26	0,59	0,33	0,32
Non-ICT capital services	0,87	0,76	0,77	0,60	0,69
TFP	0,88	0,75	0,38	0,14	0,88
<i>ICT capital services contribution (in %)</i>	<b>12,34%</b>	<b>16,03%</b>	<b>22,43%</b>	<b>21,16%</b>	<b>11,07%</b>

<b>UNITED STATES</b>	<b>1985-1990</b>	<b>1990-1995</b>	<b>1995-2000</b>	<b>2000-2005</b>	<b>2005-2007</b>
<i>Growth rate (annual average rates,%)</i>					
<b>GDP volume</b>	<b>3,06</b>	<b>2,18</b>	<b>4,08</b>	<b>2,29</b>	<b>2,21</b>
<i>Contribution to GDP growth (% points)</i>					
Hours worked	1,26	0,65	1,32	0,00	0,91
Labour composition change	0,15	0,20	0,21	0,22	0,22
ICT capital services	0,58	0,57	1,16	0,44	0,48
Non-ICT capital services	0,89	0,72	0,98	0,59	0,69
TFP	0,18	0,04	0,41	1,05	-0,09
<i>ICT capital services contribution (in %)</i>	<b>18,90%</b>	<b>26,15%</b>	<b>28,44%</b>	<b>19,26%</b>	<b>21,55%</b>

Source: EU KLEMS (2009)

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invention of Internet-enabled mobile phones is less important than that of Internet, most of them still anticipated high rate of labour productivity growth as did for instance Jorgenson, Ho and Stiroh (2003 [133]). Instead of which, as we will see hereafter, labor productivity accelerated further over the the next several years in the United States and these observations tend to support the hypothesis of a structural change and will need further explanation than a “simple ICT-centered story” in the words of Oliner et al. (2008 [174])

We shall now see that the observed facts have not been as anticipated, especially in the United States.

**Observations** Cette, Kocoglu, Mairesse, 2009 [47] observe that the GDP increase slowed during 2000-2006 and fell to its pre-1995 level on average. Admittedly, they find a slowdown in productivity in France (because of MFP contribution) and in United-Kingdom (because of ICT capital deepening) (0.3% per year) however, they found a slightly acceleration in US (because of capital deepening).

The change of the nature of the labor productivity growth in 2000 leads Oliner, Sichel, Stiroh (2007, 2008, [173] [174]) to turn again to the industry origins of US productivity growth<sup>17</sup> distinguishing three categories of industries in their approach: ICT-producing<sup>18</sup>, ICT-using<sup>19</sup> and other industries. Unlike the previous period, they find that after 2000, the contribution from ICT capital deepening, as well as from the MFP growth in ICT producing sectors, are greatly reduced but this is due to non-ICT capital<sup>20</sup> deepening and MFP growth in non-ICT sectors that support productivity growth. The drop in ICT contributions was more than offset by these other factors and labor productivity accelerated another 0,35% after 2000 in spite of what it was expected. These results are in line with Jorgenson, Ho and Stiroh (2008 [136]) who proceed with a similar study.

Albeit, during 1995-2000, the contribution of ICT-producing and -using industries was larger than total productivity growth and they were responsible for the post-1995 acceleration in productivity, even if they still contribute, for a large part, to productivity growth (ICT producers accounted for 19% of productivity growth and for only 4.5% of the VA), they no longer represent the main component.

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<sup>17</sup>The average labor productivity (ALP) is measured both in term of value added and in term of gross output per hour worked. The post-1995 productivity gains are strongest for gross output but the post-2000 gains are strongest for value added. Finally, in their model, they give priority to the measure in gross output per hour worked, given that there is less bias.

<sup>18</sup>According to the US approach (or functional approach describe above, section 3.2.1 on page 100), comprised of computer and electronics products, publishing including software, information and data processing services, and computer system design and related services.

<sup>19</sup>They identify industries as ICT-using if their ICT capital income share (nominal ICT capital income as a share of nominal nonresidential capital income) is above the median for all industries, excluding the ICT-producing industries

<sup>20</sup>other tangible capital

In fact the small acceleration could be due to the reallocation of materials and hours worked, which reflects the increase in competitive pressure.

So, according to most studies, the analysis of labor productivity growth between 1990 and 2005 tells us three different stories, depending on whether we look before 1995, between 1995 and 2000 or after 2000. Nevertheless, if we assume that ICT could be seen as a GPT and involves other innovation and a delay in implementation, it should be more appropriate to consider a longer period as a whole. Furthermore, the use and production of ICT capital accounted for about two-thirds of the labor productivity growth during 1995-2005, thus it is difficult to conclude with a non-determinant role of ICT in the post-2000 productivity growth in the sense that ICT installed during the end of the 1990s could have induce delayed variation of other complementary factors of growth, such as intangible capital or innovation.

### 4.3.3 The global contribution of ICT

If we look at the period 1980-2006, according to Cette et al. (2009 [47]) (see table 4.6), we see that the average annual output growth is higher in the United States than in France or in United Kingdom but the hourly labour productivity growth is higher in these two last countries. Over this period, Cette et al. (2009 [47]) find that the contribution of ICT capital is greater than that of non-ICT capital in US but the reverse in the three other countries. However, the average level of ICT contribution is relatively comparable between these countries, indeed the ranges of these contributions are from 0.3 to 0.5%points. Thus, over this period we cannot really see the superiority of the United States, except in term of output growth.

However, since 1995, if we focus on the last two phases, the US advantage is more evident. Indeed, if we refer to Van Ark, OMahony, Timmer (2008 [230]) results (see table 4.5) we can see that, over the period 1995-2004, the output growth rate is largely higher in United States than in Europe and is also higher than in all European countries considered in the study, except Finland. Furthermore, during this period, the average labour productivity contribution is twice as high in US than in Europe (3.0%points compared to 1.5%points) and the difference comes from ICT capital deepening and multifactor productivity. So, the difference in contribution of “knowledge economy” accounts for the whole gap in labor productivity contribution. At the country level, only Denmark and United Kingdom have a better ICT contribution than U.S. and only Finland has a higher contribution from the

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“knowledge economy”. This table also highlights the great heterogeneity between European countries, especially we observe that the two countries of the *Olive Belt* that are in the list, Italy and Spain, have a negative contribution from the “knowledge economy”. The countries with the most knowledge-based economy are Finland, United Kingdom, Austria and Netherlands and they are also those whose labour productivity contribution is closer to that of the U.S..

Moreover, it seems possible to locate the US-EU imbalance at the sectoral level. Indeed “the relative disadvantage of the European economy is concentrated in a small group of industries which are either producers or heavy users of ICT: wholesale and retail trade; financial services, real estate and other business activities and ICT manufacturing” (Dimelis and Popaioanou, 2010 [75]). Not only are these sectors more efficient in U.S. but also they have a larger weight in the economy than in Europe. So “these industries are responsible for the largest part of the MFP growth differences between the U.S. and the EU as well as for the higher contribution of ICT capital” (Dimelis and Popaioanou reminding European Commission, 2007). So while in the United States, the Baumol disease, that occurred in service industries, has been obviously cured since 1995 (Triplett and Bosworth, 2006 [220]), it seems not be the case in Europe. Manufacturing sectors are still the main contributors to productivity growth in Europe despite their lower weight in value added compared to service sectors, whereas U.S. multifactor productivity is driven by finance and business industries, according to Triplett and Bosworth (2006 [220]) and Jorgenson et al. (2005 [134]). The gap in the productivity growth contribution between EU and U.S. is especially strong in trade services and in finance and business services.

So in the United States, the retail sector underwent a substantial transformation adopting ICT, commonly referred as the “lean retailing system” (Abernathy et al. 2000 [2]): “The retail industry has changed from a low-tech industry where workers mainly shift boxes from the producer to the consumer depending on availability in stock, into an industry whose main activity is trading information by matching the production of goods and services to customer demand on a continuous basis” as explain Van Ark et al. (2008 [230]). Is this the reason that Europe is falling behind in this transformation?

Nevertheless, we must remain nuanced since this disease unevenly affected the European member states. Van Ark et al. (2008 [230]) emphasize that whereas “Germany, Italy, and Spain show almost zero contributions from market services to aggregate labor productivity”, “market services in United Kingdom and the Netherlands contributed almost as much to aggregate labor productivity growth as in the US.” (“mainly due to strong performance in trade and business services industries”)

In view of these observations, we can conclude that the catch up process that Europe underwent since the 1950s stopped in the middle 1990s. Like in the early 20th century, with electricity, the Old Continent is missing the train of technology today. In fact, Europe is worse than America both at inventing ICTs and also at adopting and using them (Bloom et al., 2007 [27]).

Notwithstanding, if the analysis of the source of the U.S. performance and of the gap between Europe and US is clear over the period 1995-2000 and attributes a major role to the production and the adoption of ICT, the interpretation is not so obvious after 2000. Indeed, given that the weight of ICT investment declined significantly in all countries after the burst of the dotcom bubble, their direct effect is not enough to justify neither the US productivity acceleration nor the expansion of the gap between US and Europe. We cannot, however, exclude the hypothesis of a predominant role of ICT. Instead, the economic literature suggests the inclusion of complementary elements, such as investment in other intangible assets as we will see thereafter.

### 4.4 Conclusion

So, after observation of the data on ICT investment across countries and industries in section 4.2, we have reviewed in section 4.3, studies that assessed the impact of ICT on economic and productivity growth.

The first section highlighted the recent strong acceleration in ICT adoption in all western economies and especially of IT and software components. We have also shown that the intensity of ICT investments is heterogeneous across sectors and, in particular, a few sectors become highly ICT intensive such as *Financial intermediation, Wholesale and retail trade and Real estate, renting and business services*. This leads to define three categories of industries: ICT producing industries; ICT using industries, including the most ICT intensive sectors, and non-ICT industries which includes all the remaining industries.

Following the observation of a long period of productivity stagnation, despite the wide proliferation of computers and the speed of technical progress in this field, which underlines a “productivity paradox”, economists sought to assess the impact of ICTs on economic and productivity growth in the growth accounting framework. The second part showed that these studies are relatively consistent and identify three phases during which the importance and the nature of the role of ICT have changed. During the first period, until 1995, the economic impact of ICT was confined to ICT producing sectors and

Table 4.5: Contributions to growth of real output in the market economy, EU economies and US 1995-2004

	Growth rate of output			Output contribution from			Labor productivity contribution from					Knowledge economy
	1=2+3	Hours worked	Labor productivity	Labor composition	ICT capital per hour	Non-ICT capital per hour	MFP	4	5	6	7	
Austria	2.6	0.4	2.2	0.2	0.6	0.1	1.2	0.2	0.6	0.1	1.2	2.1
Belgium	2.4	0.6	1.8	0.2	0.7	0.4	0.4	0.2	0.7	0.4	0.4	1.4
Denmark	2.3	0.9	1.4	0.3	1.2	0.3	-0.4	0.3	1.2	0.3	-0.4	1.1
Finland	4.4	1.1	3.3	0.1	0.5	-0.1	2.8	0.1	0.5	-0.1	2.8	3.4
France	2.5	0.4	2.0	0.4	0.5	0.4	0.8	0.4	0.5	0.4	0.8	1.6
Germany	1.0	-0.6	1.6	0.1	0.5	0.6	0.3	0.1	0.5	0.6	0.3	1.0
Italy	1.4	1.0	0.5	0.1	0.2	0.6	-0.4	0.1	0.2	0.6	-0.4	-0.1
Netherlands	2.8	0.8	2.0	0.2	0.6	0.1	1.0	0.2	0.6	0.1	1.0	1.9
Spain	3.6	3.3	0.2	0.4	0.3	0.4	-0.9	0.4	0.3	0.4	-0.9	-0.2
United Kingdom	3.3	0.7	2.7	0.5	1.0	0.4	0.7	0.5	1.0	0.4	0.7	2.2
European Union	2.2	0.7	1.5	0.2	0.5	0.5	0.3	0.2	0.5	0.5	0.3	1.1
United States	3.7	0.6	3.0	0.3	0.8	0.4	1.4	0.3	0.8	0.4	1.4	2.6
Standard Deviation**	1.0	0.9	1.0	0.1	0.3	0.2	1.0	0.1	0.3	0.2	1.0	1.1

\*\*Standard Deviation for European countries and the United States

Source: Van Ark, OMahony, Timmer (2008 [230])

Table 4.6: Average annual labor productivity growth and contributions (%per year)

	United States				Japan					
	1980-2006	1980-1990	1990-1995	1995-2000	2000-2006	1980-2006	1980-1990	1990-1995	1995-2000	2000-2006
Output growth	3.1	3.3	2.5	4.1	2.4	2.3	3.9	1.5	1.0	1.5
Labor productivity per employee	1.6	1.4	1.2	2.0	1.9	1.8	2.7	0.9	1.0	1.6
Labor productivity* growth	1.6	1.4	1.0	2.0	2.2	2.4	3.1	2.4	1.7	2.0
Capital deepening	0.7	0.6	0.5	0.8	1.0	1.4	1.6	1.9	1.5	0.8
ICT capital	0.4	0.3	0.3	0.7	0.4	0.4	0.3	0.4	0.6	0.3
Non-ICT capital	0.3	0.3	0.2	0.1	0.6	1.4	0.3	1.5	0.9	0.5
TFP growth	0.9	0.8	0.5	1.2	1.2	1.0	1.5	0.5	0.2	1.2
	France				United Kingdom					
	1980-2006	1980-1990	1990-1995	1995-2000	2000-2006	1980-2006	1980-1990	1990-1995	1995-2000	2000-2006
Output growth	2.1	2.4	1.2	2.8	1.7	2.5	2.6	1.7	3.2	2.5
Labor productivity per employee	1.5	2.1	1.2	1.2	1.1	2.0	1.9	2.5	1.9	1.6
Labor productivity* growth	2.2	2.9	1.8	1.9	1.6	2.2	2.0	2.8	2.3	2.0
Capital deepening	0.9	1.2	1.0	0.5	0.7	1.1	1.0	1.5	1.1	0.9
ICT capital	0.3	0.3	0.2	0.3	0.3	0.5	0.4	0.4	0.7	0.4
Non-ICT capital	0.6	0.9	0.8	0.2	0.4	0.6	0.6	1.1	0.4	0.5
TFP growth	1.3	1.7	0.8	1.4	0.9	1.1	1.0	1.3	1.2	1.1

\*hourly productivity

 Source: *Cette Kocoglu and Mairesse (2009 [47])*



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the weight of the service industries, which was affected by Baumol's disease because of their non progressiveness, strangling the release of productivity growth. Afterwards, between 1995 and 2000, we observe a revival of productivity growth in the United States but not in Europe. Growth accounting analyzes show the prominent role of ICTs in the U.S. productivity growth resurgence. Jorgenson et al. (2008 [136]) show that ICT contributed to nearly 60% of the labour productivity<sup>21</sup> growth between 1995-2000 (see table 4.3). Moreover, most studies agree on the fact that the productivity gap between US and Europe is attributable to the slower emergence of the knowledge economy<sup>22</sup> in Europe. Van Ark et al. (2003 [229]) also show that, during this period the US-EU divergence in ICT contribution is more a within-industry effect than a between-industry effect, in the sense that the two most important sources of divergence are the weight of the ICT producing industries and the higher productivity growth in ICT using industries. Thus this gap is reflected in "lower growth contribution of ICT, the relatively small share of technology-producing and a slower multifactor productivity growth in Europe" (Van Ark et al., 2008 [230]).

Finally, after 2000, an event again disturbed analysts: the dotcom crisis. After a period of growing euphoria concerning ICT investments, the burst of the dotcom bubble significantly contracted ICT investments during the following several years. Thus, according to the results of previous studies, most economists expected a slowdown in labour productivity. Instead, productivity continued to accelerate in the United States. So the two "productivity paradoxes" show that ICT adoption is characterized by some operating delays or that it is not sufficient to completely explain the productivity growth in the recent decades.

Thereby, in order to comprehend the full potential of ICT, it is necessary to identify and assess the underlying mechanisms. And among the reasons to the productivity growth resurgence we have to distinguish between those directly or indirectly based on ICT and those a priori unrelated to ICT. Among the formers, we can mention two further explanations other than the increase in ICT capital accumulation and ICT production:

- A first one is that "ICT investment proxies for complementary investments in intangible capital" (Brynjolfson and Hitt, 2000 [38] or Brynjolfson and Saunders, 2009 [40]) and thus growth accounting should be reappraised taking into account such investments;

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<sup>21</sup>Either across capital deepening or across MFP gains

<sup>22</sup>The weight of the knowledge economy as measured by the contribution of ICT capital and MFP

- A second one “identifies ICT as a general purpose technology (GPT) that spurs further innovation over time in a wide range of industries, ultimately boosting growth in MFP” (Bresnahan and Trajtenberg, 1995 [31]) in the sense that the large diffusion of a GPT induces innovation opportunities. More precisely, Bresnahan and Trajtenberg identify two sets of externalities: a vertical set, between GPT producers and GPT users, and a horizontal set, between GPT users.

The McKinsey Global Institute (2001 [125]) confirms that ICT investment leads to higher productivity, especially if the investment is accompanied by complementarity investments in organizational change, which suggests that these two productivity growth explanations put forward are in fact strongly linked.

These ICT-related explanations also highlight delay between ICT investments and this form of induced growth since the installed intangible capital needs time to become operational and innovations occur several years after R&D investments. Indeed “returns to new ICT investments are likely to be delayed until complementary investments, organisational changes and skills training have been realized to maximise the returns from ICT” (Black and Lynch, 2001 [23]). This implies, on one hand, greater returns for leader countries in ICT adoption and, on the other hand, the productivity effects are discernible some time after the investment. Then, first, the U.S. advance could be partly explained by the earlier adoption of ICT and, second, a part of the productivity growth after 2000 could be due to the ICT investment that occurred before 2000. This gives some explanations of why both the productivity resurgence and slowdown are delayed with respect to the start or the cessation of the ICT investment. In other words, this could explain why we observe a “productivity paradox” (or “Solow paradox”) in the early 1990s and why after 2000 productivity growth even accelerates. Actually in the words of Helpman and Trajtenberg (1994 [118] or 1996 [119, 120]), the first period, before 1995 should correspond to “*the time to sow*” and the period after 1995 should correspond to “*the time to reap*”.

Consequently, in order to highlight the impact of ICT as a general purpose technology, we have to take into account a large period preceding the one that we want to explain. The growth resurgence in the second half of the 1990 was conditioned by investment engaged in the early 1990s and, in the same way, the continuation of productivity growth after 2001 is partly a consequence of researches and developments that started before 2000.

What is more, if complementary intangible investment is supposed to be proxied by ICT investment, since ICT investment has decreased since several years ago, we can deduce that intangible investment has been quite sluggish since 2000. This would lead us to expect that labor productivity would slow down over recent years.

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Obviously this interpretation is subject to limitations and is only complementary to other explanations unrelated to ICT. In particular, Gordon (2003 [92]) shows that the rapid productivity gains after 2000 were also partly due to restructuring and cost cutting in some industries. In fact he highlights that industries that saw the sharpest declines in profits from the late 1990s through 2001 also tended to post the largest gains in labor productivity in the early 2000s. So he concludes that “savage cost cutting and layoffs” explains a large part of the surge in productivity in the early 2000s. Moreover, Bosworth and Triplett (2007 [29]) indicate that reallocations of both material and labor inputs have been one of the main contributors to labor productivity growth since 2000. In this way they attribute an important role to the flexibility of the US economy to support productivity growth by shifting resources between industries.<sup>23</sup>

For that purpose in the following chapters we will investigate four main issues. Chapter 5 focuses on the importance of cost optimization and horizontal externalities in sectors strongly linked to ICT diffusion. Whereas, in the third part of the thesis, we will first focus on the impact of the inclusion of intangible capital on growth accounting by reassessing the output and, in a second step, we will endeavor to reveal complementarities between ICT investments and intangible assets. Consequently, while this second part deals with the ubiquitous nature of ICT, the third will address this technology as an enabling technology that requires additional investment.

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<sup>23</sup>We may mention other studies such as Baily (2004 [12]) who analyses the impact of competitive pressures that gradually increased during the 1970s and the 1980s; Schweitzer (2004 [204]), who underlines the reorganization of production processes without hiring or Schreft and Singh (2003 [199]) who show that the adoption of an efficient strategy is more executable in an environment with more flexible and efficient labor markets.

## 4.5 Appendix

Table 4.7: ICT capital compensation and its components in percentage of GDP

		1970	1980	1985	1990	1995	2000	2005
<b>Austria</b>	<i>Communication Equipment</i>		0,9	0,9	0,9	0,9	0,9	0,4
	<i>Computing Equipment</i>		0,4	0,6	0,7	0,7	0,9	0,8
	<i>Software</i>		0,1	0,2	0,3	0,4	0,8	0,9
	<b>Total ICT</b>		<b>1,4</b>	<b>1,7</b>	<b>2,0</b>	<b>1,9</b>	<b>2,6</b>	<b>2,1</b>
<b>Germany</b>	<i>Communication Equipment</i>					0,6	0,7	0,4
	<i>Computing Equipment</i>					0,7	1,1	0,7
	<i>Software</i>					0,7	1,0	1,0
	<b>Total ICT</b>					<b>2,1</b>	<b>2,8</b>	<b>2,1</b>
<b>Finland</b>	<i>Communication Equipment</i>	0,3	0,4	0,6	0,8	0,7	1,3	1,0
	<i>Computing Equipment</i>	0,6	0,5	0,7	0,9	1,0	0,5	0,3
	<i>Software</i>	0,1	0,5	0,6	1,0	1,2	1,4	1,8
	<b>Total ICT</b>	<b>0,9</b>	<b>1,4</b>	<b>1,9</b>	<b>2,7</b>	<b>2,9</b>	<b>3,1</b>	<b>3,1</b>
<b>France</b>	<i>Communication Equipment</i>	0,5	0,4	0,5	0,5	0,5	0,5	0,4
	<i>Computing Equipment</i>	0,4	0,3	0,5	0,6	0,5	0,7	0,5
	<i>Software</i>	0,3	0,5	0,8	0,9	1,0	1,8	1,7
	<b>Total ICT</b>	<b>1,2</b>	<b>1,2</b>	<b>1,7</b>	<b>2,0</b>	<b>1,9</b>	<b>3,0</b>	<b>2,6</b>
<b>Italy</b>	<i>Communication Equipment</i>	0,8	0,9	0,8	0,9	0,9	1,0	0,7
	<i>Computing Equipment</i>	0,4	0,6	0,7	0,6	0,4	0,7	0,5
	<i>Software</i>	0,0	0,1	0,4	0,6	0,7	0,9	0,8
	<b>Total ICT</b>	<b>1,2</b>	<b>1,7</b>	<b>1,8</b>	<b>2,2</b>	<b>2,0</b>	<b>2,5</b>	<b>2,0</b>
<b>Netherland</b>	<i>Communication Equipment</i>	0,5	0,5	0,6	0,7	0,8	0,7	0,6
	<i>Computing Equipment</i>	0,3	0,5	0,9	1,1	1,0	1,1	1,0
	<i>Software</i>	0,1	0,3	0,6	0,9	0,8	1,6	1,5
	<b>Total ICT</b>	<b>0,9</b>	<b>1,3</b>	<b>2,0</b>	<b>2,7</b>	<b>2,6</b>	<b>3,5</b>	<b>3,1</b>
<b>Spain</b>	<i>Communication Equipment</i>	1,1	0,6	0,9	1,2	0,8	1,2	1,0
	<i>Computing Equipment</i>	0,6	0,5	0,9	0,9	0,7	0,8	0,5
	<i>Software</i>	0,1	0,2	0,5	0,7	0,7	1,0	1,2
	<b>Total ICT</b>	<b>1,8</b>	<b>1,3</b>	<b>2,2</b>	<b>2,8</b>	<b>2,2</b>	<b>2,9</b>	<b>2,8</b>
<b>United Kingdom</b>	<i>Communication Equipment</i>	0,2	0,3	0,4	0,4	0,7	1,1	0,5
	<i>Computing Equipment</i>	0,6	0,5	1,0	1,2	1,4	1,6	1,1
	<i>Software</i>	0,2	0,4	0,7	1,2	1,4	2,0	1,7
	<b>Total ICT</b>	<b>1,0</b>	<b>1,2</b>	<b>2,1</b>	<b>2,8</b>	<b>3,4</b>	<b>4,7</b>	<b>3,3</b>
<b>Australia</b>	<i>Communication Equipment</i>	0,7	0,7	0,7	0,5	0,4	0,7	0,6
	<i>Computing Equipment</i>	0,3	0,7	1,0	1,0	1,5	1,5	1,5
	<i>Software</i>	0,0	0,3	0,6	1,0	1,2	1,7	1,3
	<b>Total ICT</b>	<b>1,1</b>	<b>1,6</b>	<b>2,3</b>	<b>2,6</b>	<b>3,0</b>	<b>3,8</b>	<b>3,5</b>
<b>Japan</b>	<i>Communication Equipment</i>		0,6	0,5	0,7	0,7	0,8	0,5
	<i>Computing Equipment</i>		0,6	1,1	1,5	1,3	1,3	0,7
	<i>Software</i>		0,2	0,4	0,6	0,7	1,2	1,4
	<b>Total ICT</b>		<b>1,3</b>	<b>2,1</b>	<b>2,8</b>	<b>2,8</b>	<b>3,3</b>	<b>2,6</b>
<b>United States</b>	<i>Communication Equipment</i>		0,9	1,0	0,9	0,9	1,4	0,7
	<i>Computing Equipment</i>		0,5	0,9	0,8	1,0	1,1	0,7
	<i>Software</i>		0,4	0,7	1,1	1,3	2,2	2,0
	<b>Total ICT</b>		<b>1,9</b>	<b>2,6</b>	<b>2,7</b>	<b>3,3</b>	<b>4,7</b>	<b>3,4</b>

Source: EUKLEMS

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CHAPTER 4. ICT DIFFUSION AND DIRECT CONTRIBUTION ON GROWTH

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Table 4.8: ICT capital compensation and its componants in percentage of GDP

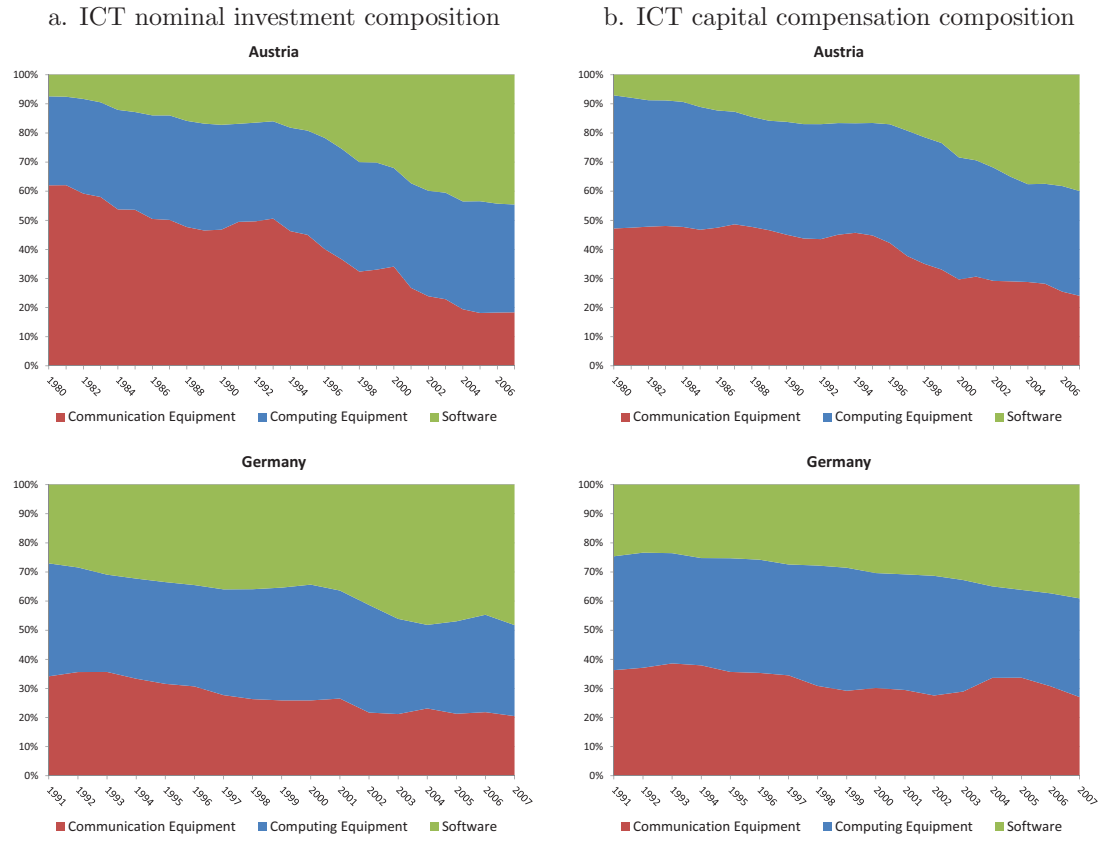
		1970	1980	1985	1990	1995	2000	2005
<b>Austria</b>	<i>Communication Equipment</i>		0,7	0,9	1,1	1,2	0,9	0,9
	<i>Computing Equipment</i>		0,7	0,8	1,0	1,1	1,3	1,2
	<i>Software</i>		0,1	0,2	0,4	0,5	0,9	1,3
	<b>Total ICT</b>		<b>1,5</b>	<b>1,9</b>	<b>2,5</b>	<b>2,8</b>	<b>3,1</b>	<b>3,4</b>
<b>Germany</b>	<i>Communication Equipment</i>					1,2	1,1	1,2
	<i>Computing Equipment</i>					1,3	1,4	1,1
	<i>Software</i>					0,8	1,1	1,3
	<b>Total ICT</b>					<b>3,3</b>	<b>3,6</b>	<b>3,5</b>
<b>Finland</b>	<i>Communication Equipment</i>	0,1	0,6	0,6	0,9	0,9	1,7	1,4
	<i>Computing Equipment</i>	1,6	0,8	0,9	1,2	1,2	1,0	0,4
	<i>Software</i>	0,0	0,4	0,5	1,1	1,6	2,9	2,5
	<b>Total ICT</b>	<b>1,8</b>	<b>1,8</b>	<b>2,0</b>	<b>3,1</b>	<b>3,6</b>	<b>5,6</b>	<b>4,4</b>
<b>France</b>	<i>Communication Equipment</i>	0,3	0,5	0,6	0,8	0,7	0,9	0,7
	<i>Computing Equipment</i>	0,5	0,4	0,5	0,8	0,7	0,8	0,7
	<i>Software</i>	0,2	0,5	0,8	1,2	1,1	2,0	2,2
	<b>Total ICT</b>	<b>1,0</b>	<b>1,4</b>	<b>1,9</b>	<b>2,8</b>	<b>2,5</b>	<b>3,7</b>	<b>3,5</b>
<b>Italy</b>	<i>Communication Equipment</i>	0,7	0,8	0,7	0,8	0,9	1,1	1,1
	<i>Computing Equipment</i>	0,6	0,9	0,9	0,8	0,6	0,9	0,7
	<i>Software</i>	0,2	0,1	0,3	0,7	0,8	1,0	1,1
	<b>Total ICT</b>	<b>1,5</b>	<b>1,8</b>	<b>1,9</b>	<b>2,3</b>	<b>2,3</b>	<b>2,9</b>	<b>2,9</b>
<b>Netherland</b>	<i>Communication Equipment</i>	0,4	0,5	0,6	0,9	0,9	0,9	1,0
	<i>Computing Equipment</i>	0,3	0,6	1,0	1,3	1,5	1,7	1,4
	<i>Software</i>	0,1	0,3	0,5	1,0	1,1	1,7	2,1
	<b>Total ICT</b>	<b>0,8</b>	<b>1,5</b>	<b>2,2</b>	<b>3,2</b>	<b>3,5</b>	<b>4,3</b>	<b>4,5</b>
<b>Spain</b>	<i>Communication Equipment</i>	1,5	1,5	1,6	1,6	1,5	1,6	1,4
	<i>Computing Equipment</i>	1,3	0,9	1,3	1,3	1,0	1,2	0,9
	<i>Software</i>	0,4	0,4	0,6	1,0	1,0	1,2	1,8
	<b>Total ICT</b>	<b>3,2</b>	<b>2,9</b>	<b>3,5</b>	<b>4,0</b>	<b>3,5</b>	<b>4,1</b>	<b>4,1</b>
<b>United Kingdom</b>	<i>Communication Equipment</i>	0,3	0,4	0,6	0,5	0,3	0,8	0,7
	<i>Computing Equipment</i>	1,1	1,0	1,2	1,6	2,0	2,3	1,7
	<i>Software</i>	0,3	0,5	0,7	1,1	2,0	2,1	2,6
	<b>Total ICT</b>	<b>1,7</b>	<b>1,9</b>	<b>2,4</b>	<b>3,2</b>	<b>4,3</b>	<b>5,2</b>	<b>5,0</b>
<b>Australia</b>	<i>Communication Equipment</i>	0,8	0,8	0,8	0,8	0,7	0,7	1,0
	<i>Computing Equipment</i>	0,3	0,9	0,9	1,3	2,0	2,1	2,0
	<i>Software</i>	0,0	0,3	0,5	1,1	1,4	1,8	1,8
	<b>Total ICT</b>	<b>1,1</b>	<b>2,0</b>	<b>2,2</b>	<b>3,2</b>	<b>4,1</b>	<b>4,6</b>	<b>4,8</b>
<b>Japan</b>	<i>Communication Equipment</i>		0,7	0,6	0,8	0,9	1,3	0,9
	<i>Computing Equipment</i>		0,9	1,2	1,7	1,7	1,7	1,2
	<i>Software</i>		0,2	0,4	0,8	1,0	1,6	2,1
	<b>Total ICT</b>		<b>1,8</b>	<b>2,2</b>	<b>3,3</b>	<b>3,6</b>	<b>4,7</b>	<b>4,3</b>
<b>United States</b>	<i>Communication Equipment</i>		0,9	1,1	1,4	1,5	1,4	1,4
	<i>Computing Equipment</i>		0,9	1,5	1,3	1,6	1,8	1,2
	<i>Software</i>		0,6	0,9	1,5	1,8	2,3	2,6
	<b>Total ICT</b>		<b>2,4</b>	<b>3,4</b>	<b>4,2</b>	<b>4,9</b>	<b>5,4</b>	<b>5,2</b>

Source: EUKLEMS

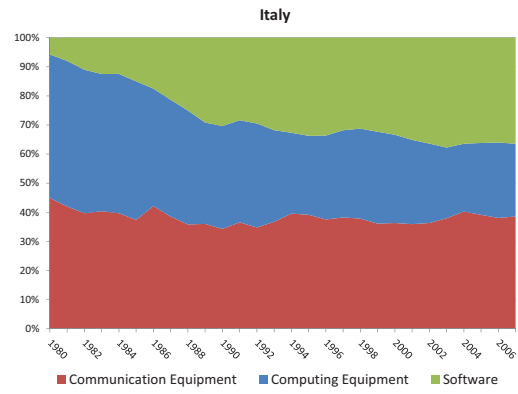
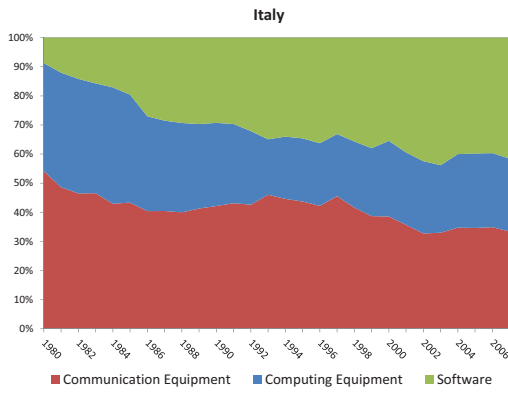
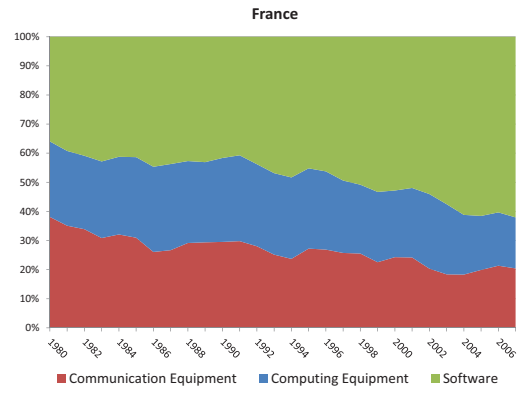
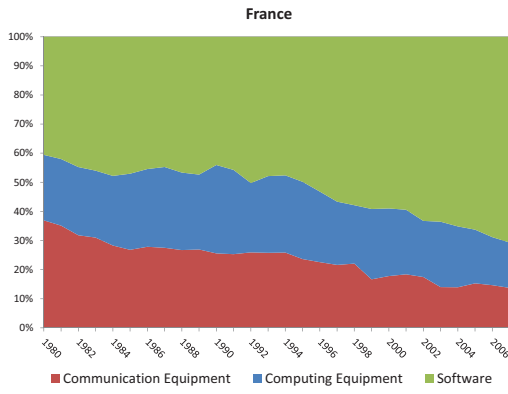
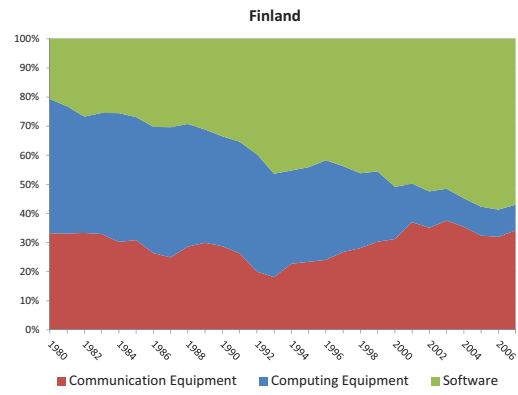
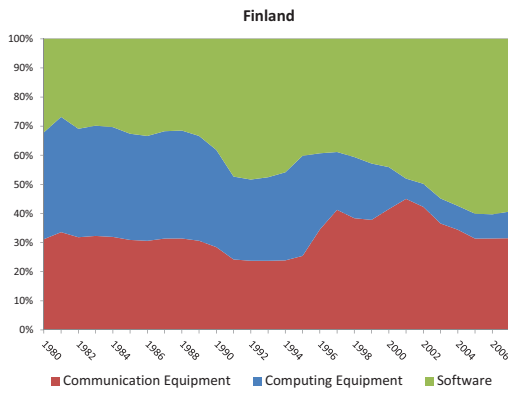
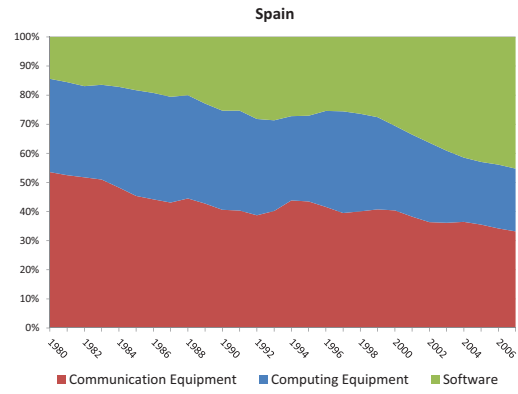
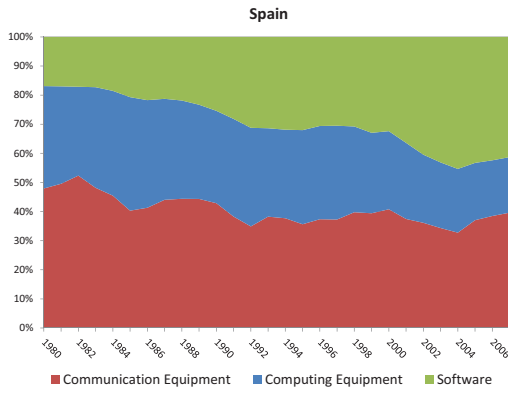
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Figure 4.5: ICT composition (Based on EUKLEMS data)



CHAPTER 4. ICT DIFFUSION AND DIRECT CONTRIBUTION ON GROWTH



## CHAPTER 4. ICT DIFFUSION AND DIRECT CONTRIBUTION ON GROWTH

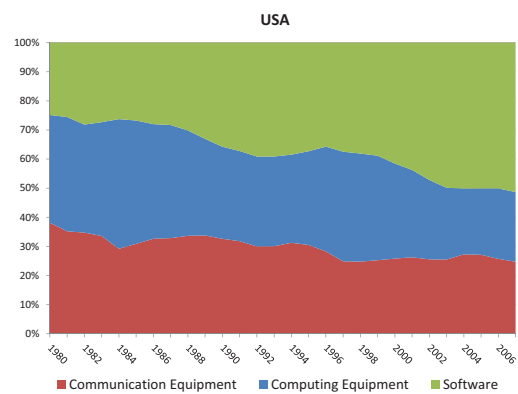
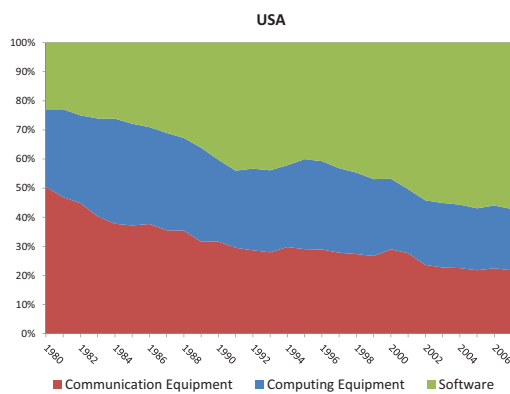
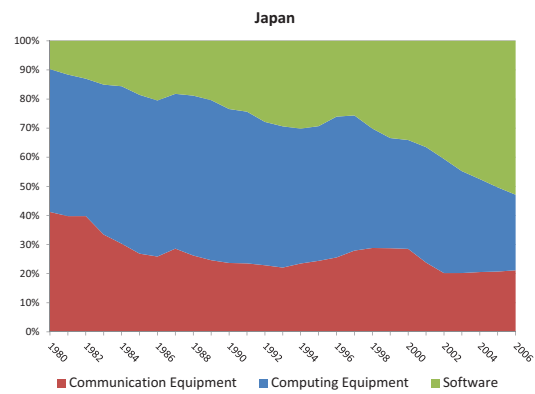
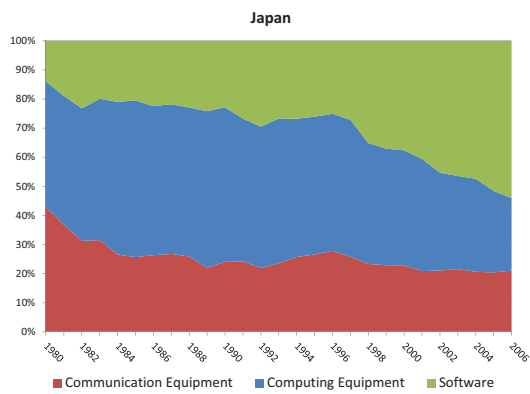
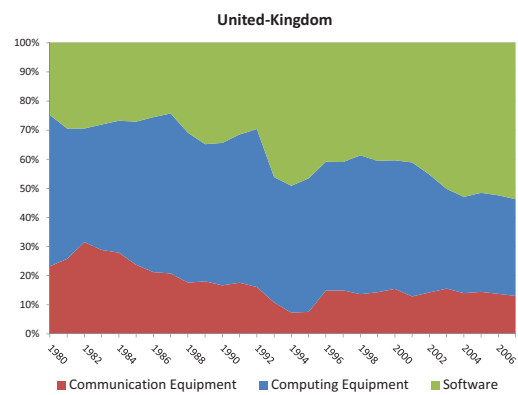
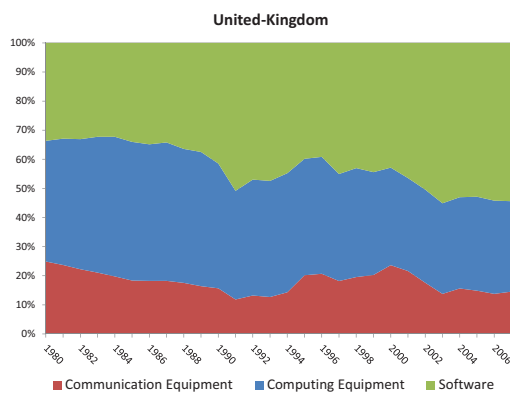
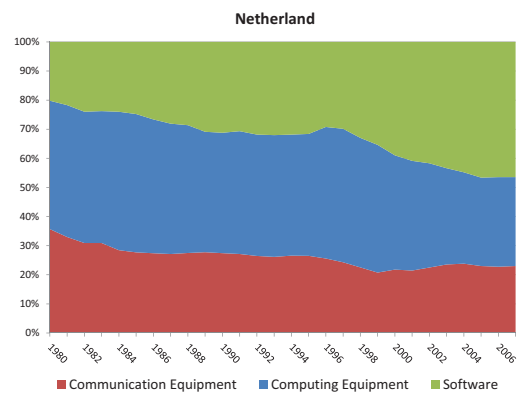
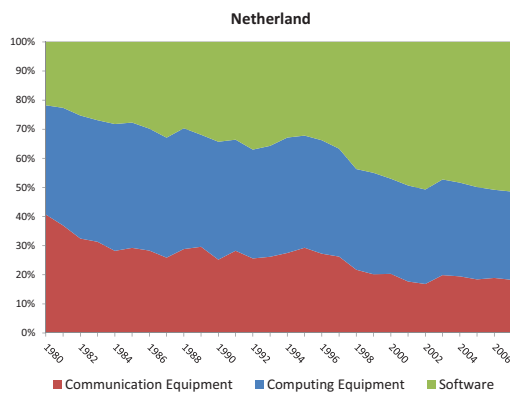
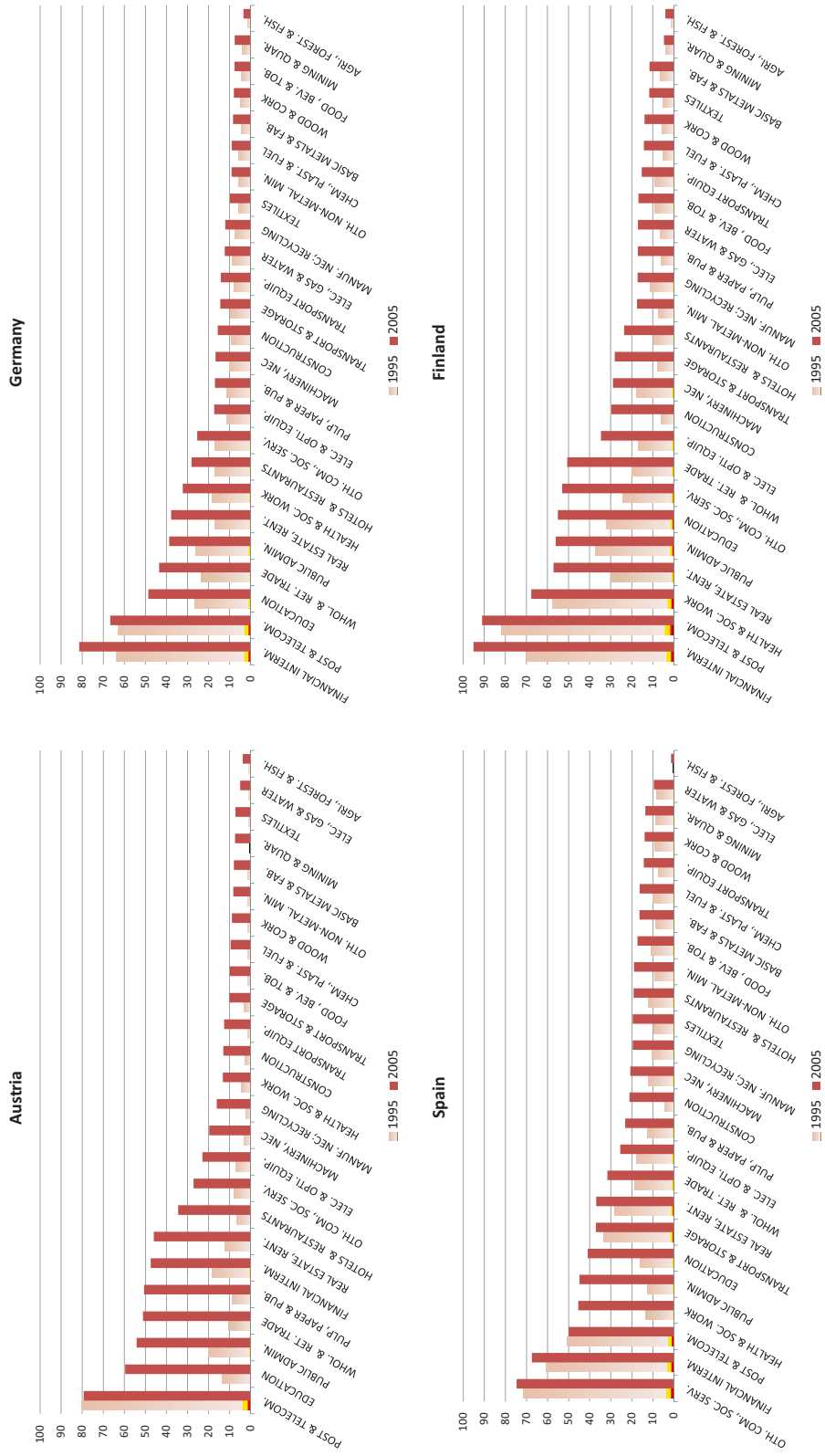


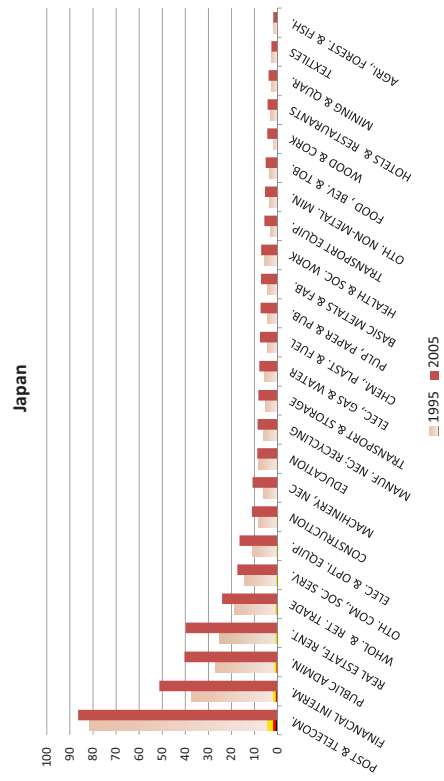
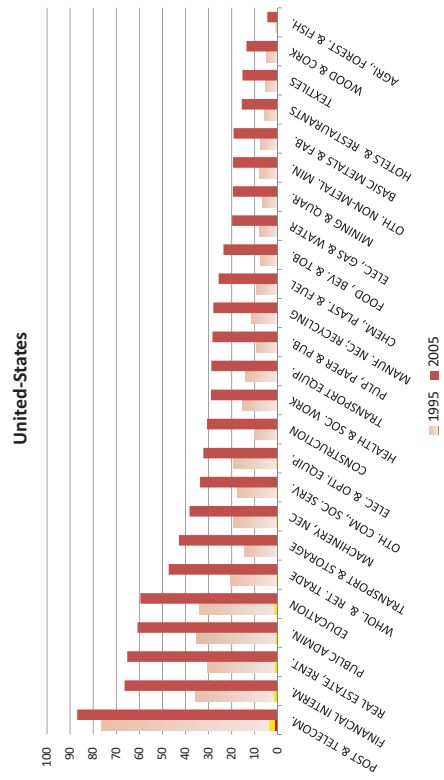


Figure 4.6: Shares of the ICT capital in total capital compensation (except Residential and Other Construction) per sector in %



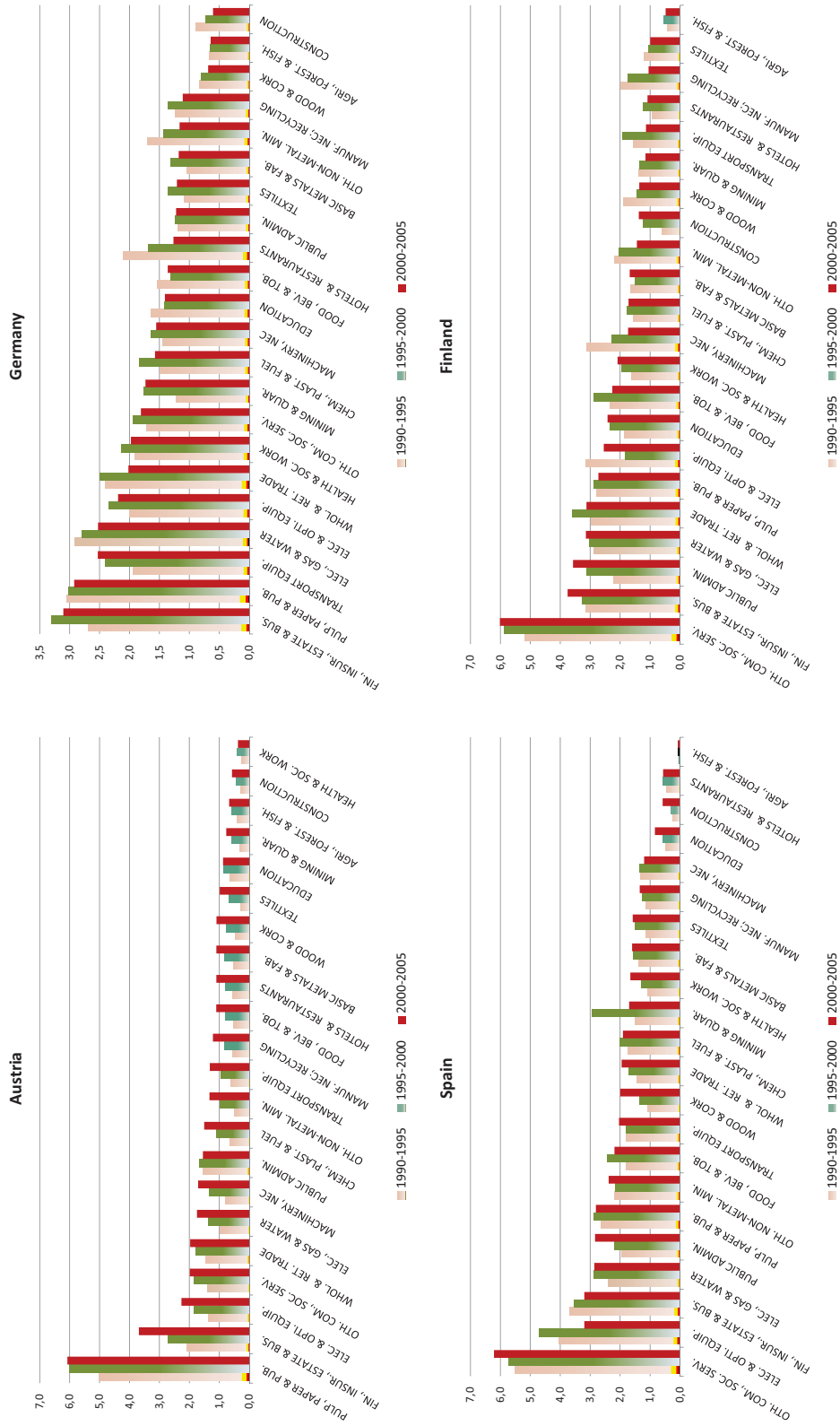


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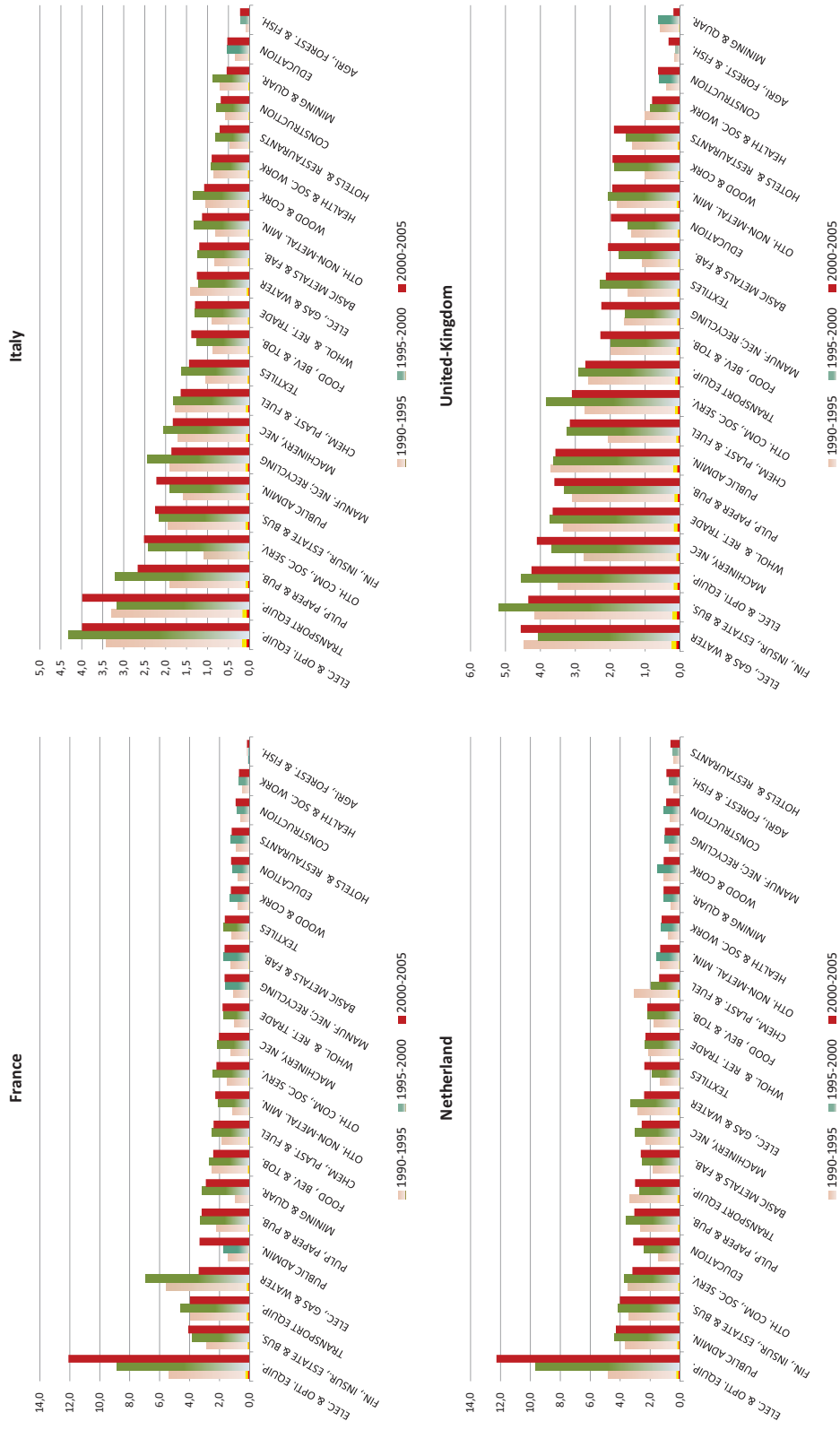


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Figure 4.7: 5 year average ICT investment rate (Inv\_ICT/VA) in %



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## Chapter 5

# Factors demand in ICT-related industries

### 5.1 Introduction

The identification of ICT as the major driver of the speedup of the economy in the second half of the 1990s led economists to anticipate a slowdown in productivity growth following the sharp pullback in ICT investment after the burst of the dotcom bubble in 2001. “Instead labor productivity accelerated further over the the next several years” in the U.S. (Oliner et al., 2008 [174]) even if it tended to slowdown after 2006. Thus the technological development and the accumulation of ICT capital are not sufficient to explain the productivity growth after 2000. “The simplest IT-centered story does not work for the period after 2000 because the contributions to growth from both the production and the use of IT decline” wrote Oliner et al. (2008 [174]). So we must distinguish between the explanations unrelated to ICT and those directly or indirectly based on ICT. The former cover a broad set of explanations such as technical progress outside ICT, cyclical phenomenons or the increase of competitive pressures that lead firms to restructure and reorganize themselves and adopt management based on profit-driven cost-cutting (Gordon, 2003 [92]). The second set of explanations includes ICT accumulation and their direct contribution to production as well as to the externalities they yield.

In the previous chapter, we have seen that producers or heavy users of ICT, especially *Electrical and Optical Equipment; Post and Telecommunication; Wholesale and Retail Trade; and Finance, Insurance,*



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*Real Estate and Business Services*, are responsible for the largest part both of the productivity growth resurgence in United States in the late 1990s and of the US-EU divergence as we can see in tables 5.1. In addition, these sectors represent the largest impact of the ICT diffusion. We thus focus, in this chapter, on these four sectors<sup>1</sup> and we try to analyze the role of ICT as well as the adjustment of inputs in production in these sectors.

The aim of this chapter is threefold. First, we study substitution or complementarity relationships, especially between ICT capital and other inputs, and we also assess ICT capital own price elasticities. Second, we identify misadjustments of inputs in the production function with respect to their optimal use. Third, we highlight externalities coming from the generalization of the use of ICT as a production factor.

On the second point, one idea underlying this paper is that the European non-ability to cure Baumol's disease may result from the adjustment rigidities of certain factors, especially of capital whose depreciation rate is low. Indeed, these rigidities can cause non-optimality which results in higher production costs. Taking into account the rigidity of capital allows us to highlight some dynamic characteristics that could be important in a context of technical change. For instance we can ask whether there is a link between the use rate of non-ICT capital and the level of ICT capital or whether the use of ICT capital is better adjusted over time. Furthermore, we show that imbalances are in fact heterogeneous in Europe and that they reflect national problems more than of generalized European problems.

For that purpose we use an approach, originally developed by Lau (1976, [147]), where rigidities are reflected in the distinction between a short-run equilibrium characterized by limited choices of employment of factors and a long-run equilibrium where all factors are adjusted to their optimum level. The distance to the optimum, measured here by the difference between the short term and the long term equilibrium, thus reveals the importance of these adjustment rigidities depending on the country. Furthermore, we found our study on the duality theory formulized by Shepard (Shepard, 1953 [207]) and on a transcendental logarithmic cost function with a quasi-fixed factor developed by Christensen, Jorgenson and Lau (1971 [50], 1973 [51]) and in Brown and Christensen (1981, [34]). Lastly we consider a production function taking into account five production factors that are low-skilled and high-skilled labor, intermediate consumption, ICT capital and non-ICT capital, the latter being

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<sup>1</sup>Actually, instead of the sector *Post and Telecommunication* we use the more aggregated sector *Transport, Storage and Telecommunication* because of data availability

considered as a quasi-fixed factor. In addition to these production inputs, the function also depends on the adoption of ICT in the other sectors.

On one hand, substitutability between factors is captured by the impact of relative prices variations on the respective use of these factors. In our paper, we provide several elasticities (Allen, Hicks-Marshall or Morishima) because each of them have different advantages and disadvantages<sup>2</sup> and they are calculated for future use in econometric models. On the other hand, ICT externalities are measured by an index of ICT capital in other sectors of the considered country. For each country, we do not take into account ICT capital of the other country in this study, we only focus on the possible intra-national and inter-sectoral externalities due to the use of ICT as a capital in production. The externalities on which we focus here correspond to horizontal externalities among GPT users as depicted by Bresnahan and Trajtenberg (1995, [31]) et Bresnahan (2003, [32]) in the sense that "the presence of a large demander changes the conditions of supply, and this may benefit other demanders". We will then see which sectors these externalities benefit.

In the second section we describe the econometric framework and its theoretical foundations. In the third section we explain the results that we can deduce from the econometric specification theoretically. Then we make a brief summary of the nature of the database that we use for these estimations. In the fifth section we proceed with the empirical analysis where we describe the results of the estimation.

## 5.2 Econometric model

### 5.2.1 Theoretical foundations of the chosen specification

We base our approach on the duality theorem which states that the cost function holds all the information on production technology, so it leads to the equivalence between the cost minimization behaviour and the production function optimization (Shephard, 1953 [207]). According to the duality theory, the unit cost of production of a constant return to scale process<sup>3</sup> is completely determined by input prices. The optimum level of these inputs are deduced from the cost minimization under the production constraint in such a way that they equalize their marginal productivity to their price. Producer behavior can then be captured by a flexible cost function. For that purpose, here we use, as a flexible form, the

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<sup>2</sup>For a discussion on the interest of each elasticity definition see Blackorby and Russel (1981, [25])

<sup>3</sup>In the case of non-constant return to scale, we can separate the decision problem into two separate problems that are on one hand the production decision given the optimal unit cost of production and, on the other hand, the optimal demand of factors given the level of production.

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Table 5.1: Sectors contribution to GDP growth

EUROPE 15	1985-1990	1990-1995	1995-2000	2000-2005	2005-2007
<i>Growth rate (annual average rates,%)</i>					
<b>GDP volume</b>	<b>3,21</b>	<b>1,64</b>	<b>2,62</b>	<b>1,56</b>	<b>2,85</b>
<i>Contribution to GDP growth (% points)</i>					
<b>ICT Producer and intensive user sectors</b>	<b>1,62</b>	<b>0,98</b>	<b>1,62</b>	<b>0,96</b>	<b>1,75</b>
Electrical and optical equipment	0,13	0,02	0,14	0,02	0,17
Wholesale and retail trade	0,37	0,20	0,29	0,17	0,25
Post and telecommunications	0,14	0,09	0,24	0,13	0,11
Fin., ins., real estate and business services	0,98	0,67	0,95	0,63	1,23
<i>ICT Producers &amp; Users contribution (in %)</i>	<b>50,5%</b>	<b>59,8%</b>	<b>61,8%</b>	<b>61,5%</b>	<b>61,4%</b>
<b>UNITED STATES</b>	<b>1985-1990</b>	<b>1990-1995</b>	<b>1995-2000</b>	<b>2000-2005</b>	<b>2005-2007</b>
<i>Growth rate (annual average rates,%)</i>					
<b>GDP volume</b>	<b>3,06</b>	<b>2,18</b>	<b>4,08</b>	<b>2,29</b>	<b>2,21</b>
<i>Contribution to GDP growth (% points)</i>					
<b>ICT Producer and intensive user sectors</b>	<b>1,76</b>	<b>1,52</b>	<b>3,05</b>	<b>1,86</b>	<b>1,67</b>
Electrical and optical equipment	0,23	0,29	0,56	0,08	0,25
Wholesale and retail trade	0,39	0,44	0,87	0,34	0,14
Post and telecommunications	0,11	0,15	0,16	0,13	0,14
Fin., ins., real estate and business services	1,04	0,63	1,45	1,31	1,13
<i>ICT Producers &amp; Users contribution (in %)</i>	<b>57,5%</b>	<b>69,7%</b>	<b>74,8%</b>	<b>81,2%</b>	<b>75,6%</b>
<i>ICT Prod. &amp; Users contribution to GDP gap (in %)</i>	-93.3%	100.0%	97.9%	123.3%	12.5%

Source: Calculations based on EU KLEMS (2009) data

CHAPTER 5. FACTORS DEMAND IN ICT-RELATED INDUSTRIES

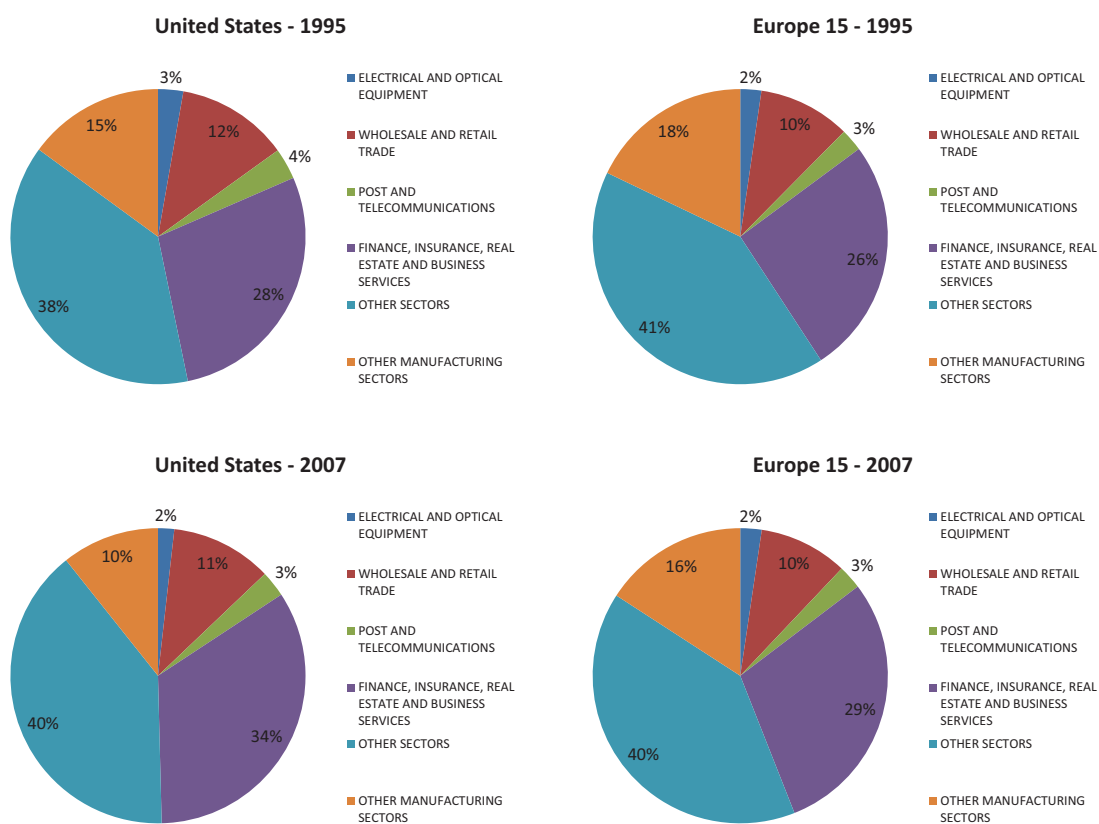
Table 5.2: Input contributions to Value Added in ICT producer and user sectors

	UNITED STATES					EUROPE 15				
	85-90	90-95	95-00	00-05	05-07	85-90	90-95	95-00	00-05	05-07
<b>Electrical &amp; Optical Equipment</b>	<b>8,24</b>	<b>10,93</b>	<b>19,82</b>	<b>4,57</b>	<b>13,93</b>	<b>4,28</b>	<b>0,90</b>	<b>5,57</b>	<b>1,22</b>	<b>7,21</b>
<i>Contribution to VA growth (% points)</i>										
Hours worked	-1,08	-1,47	0,84	-6,14	0,02	0,19	-2,96	0,00	-2,39	-0,26
Labour composition change	0,53	0,51	0,40	1,23	-0,43	0,32	0,36	0,10	0,42	0,07
ICT capital services	0,51	0,93	1,39	-0,01	0,18	0,56	0,17	0,86	0,24	0,53
Non-ICT capital services	0,37	0,78	1,30	-0,08	-0,10	1,01	0,38	0,63	0,09	-0,07
TFP	7,91	10,18	15,90	9,57	14,26	2,20	2,96	3,99	2,86	6,94
<b>ICT capital services contribution**</b>	<b>6,15%</b>	<b>8,49%</b>	<b>7,00%</b>	<b>-0,21%</b>	<b>1,32%</b>	<b>13,16%</b>	<b>18,63%</b>	<b>15,37%</b>	<b>19,76%</b>	<b>7,38%</b>
<b>Wholesale &amp; Retail Trade</b>	<b>2,99</b>	<b>3,66</b>	<b>7,09</b>	<b>2,79</b>	<b>1,27</b>	<b>3,84</b>	<b>2,01</b>	<b>2,89</b>	<b>1,67</b>	<b>2,55</b>
<i>Contribution to VA growth (% points)</i>										
Hours worked	1,12	0,56	1,10	-0,39	0,62	1,01	-0,48	0,66	0,11	0,60
Labour composition change	0,16	0,24	0,11	0,39	0,20	0,20	0,48	0,21	0,08	0,08
ICT capital services	0,45	0,57	0,89	0,50	0,57	0,39	0,24	0,58	0,32	0,32
Non-ICT capital services	0,54	0,41	0,72	0,26	0,55	0,75	0,63	0,75	0,56	0,46
TFP	0,73	1,88	4,27	2,02	-0,68	1,50	1,14	0,70	0,60	1,09
<b>ICT capital services contribution**</b>	<b>14,90%</b>	<b>15,52%</b>	<b>12,58%</b>	<b>17,91%</b>	<b>45,39%</b>	<b>10,06%</b>	<b>11,78%</b>	<b>20,07%</b>	<b>19,41%</b>	<b>12,48%</b>
<b>Post &amp; Telecommunications</b>	<b>3,30</b>	<b>4,36</b>	<b>5,11</b>	<b>4,20</b>	<b>5,04</b>	<b>5,41</b>	<b>3,56</b>	<b>9,71</b>	<b>5,20</b>	<b>4,23</b>
<i>Contribution to VA growth (% points)</i>										
Hours worked	0,00	0,77	1,25	-1,69	0,12	0,58	-1,37	0,01	-0,22	-0,51
Labour composition change	0,36	0,27	0,09	0,18	-0,14	0,24	0,10	0,11	0,34	-0,06
ICT capital services	1,07	1,57	4,31	0,52	1,32	1,62	1,21	2,79	0,97	0,85
Non-ICT capital services	0,95	0,84	0,78	0,31	0,49	1,07	0,64	0,63	0,55	0,40
TFP	0,92	0,90	-1,33	4,87	3,26	1,90	2,99	6,17	3,57	3,56
<b>ICT capital services contribution**</b>	<b>32,41%</b>	<b>36,01%</b>	<b>84,44%</b>	<b>12,38%</b>	<b>26,25%</b>	<b>29,90%</b>	<b>33,90%</b>	<b>28,74%</b>	<b>18,57%</b>	<b>20,01%</b>
<b>Finance, Ins., Real Est. &amp; Bus.</b>	<b>4,00</b>	<b>2,28</b>	<b>4,88</b>	<b>4,10</b>	<b>3,37</b>	<b>4,33</b>	<b>2,68</b>	<b>3,57</b>	<b>2,25</b>	<b>4,20</b>
<i>Contribution to VA growth (% points)</i>										
Hours worked	1,59	0,91	1,74	0,49	1,29	2,00	0,71	1,74	0,95	1,49
Labour composition change	-0,01	0,14	0,20	0,22	0,29	-0,06	0,16	-0,07	0,10	0,07
ICT capital services	1,13	0,76	1,79	0,68	0,65	0,69	0,49	0,98	0,55	0,48
Non-ICT capital services	2,17	1,46	1,90	1,23	1,06	1,64	1,56	1,51	1,09	1,30
TFP	-0,89	-1,00	-0,75	1,48	0,07	0,06	-0,24	-0,59	-0,43	0,86
<b>ICT capital services contribution**</b>	<b>28,29%</b>	<b>33,61%</b>	<b>36,74%</b>	<b>16,58%</b>	<b>19,31%</b>	<b>15,91%</b>	<b>18,21%</b>	<b>27,45%</b>	<b>24,31%</b>	<b>11,50%</b>

Source: EU KLEMS (2009)

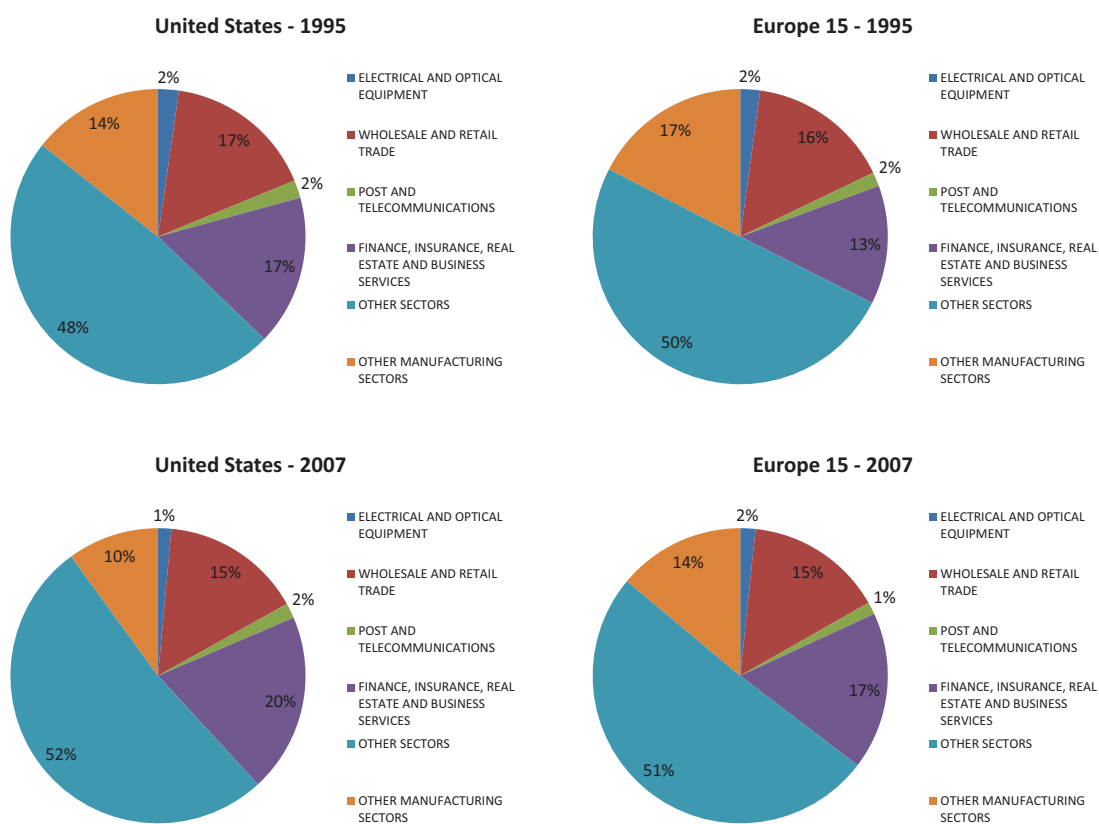
\* annual average rates in % ; \*\* in % of VA growth rate

Figure 5.1: Sectors shares in GDP value



Source: EU KLEMS data (2009 release)

Figure 5.2: Sectors shares in hours worked



Source: EU KLEMS data (2009 release)

transcendental logarithmic (translog) specification, which was introduced by Christensen, Jorgenson and Lau (1971 [50], 1973 [51]). The translog function is well adapted to our study because it does not impose any constraints or assumptions on substitutabilities between factors, since it is a log- second order approximation of any function. Therefore we can obtain potentially complementarity between factors (in opposition to the Cobb-Douglas function for instance) and the elasticities are not necessary symmetric or constant (as in the CES function). Nevertheless, we can note that other flexible functional forms of cost and production functions exist, as that described by Diewert (1971 [74]).

Furthermore, the observed levels of certain factors may differ significantly from their optimal values. The production cost is then higher than its optimal level as developed in Lau (1976, [147]) in such context of duality. In our specification, we then impose, like Brown and Christensen (1981, [34]) for the translog function, the possibility of non optimality of the level of non-ICT capital, called the quasi-fixed factor. We adopt a production function with four variable inputs, which are intermediate consumption, low-skilled labor, high-skilled labor and ICT-capital, and one quasi-fixed input which is the non-ICT capital. Therefore, we assume that the observed level of non-ICT capital is different from its optimal level because of adjustment rigidity. This may imply the distinction between the short term equilibrium where the non-ICT capital is fixed and the long term equilibrium where non-ICT capital is adjusted to its optimum. In the short term, the exogeneous variables are the prices of the variable factors, the level of the quasi-fixed capital, the level of production, the time trend and the level of externalities. The endogeneous variables are only the use of the variable inputs. In contrast, in the long run, we endogenize the level of the use of all factors depending on the prices of all the variable factors, the time trend, the level of the externalities and the user cost of the quasi-fixed capital. In the long run, quasi-fixed capital is treated as a variable input and thus its marginal productivity corresponds to its cost of use, which is not necessarily the case in the short run. We justify the choice of distinguishing non-ICT capital as a quasi-fixed factor by its depreciation rate, which is significantly lower than that of ICT-capital (this is justify in section 5.4). With this specification we take into account the greater rigidity of non-ICT capital compared to the other input.

Finally, this approach leads us to a relatively complete assessment of the production behaviour in terms of factor utilization. In the following subsection we describe the general form of a translog cost function with one quasi-fixed factor and, in the next one, the estimation method. We will also detail the constraints that we have to impose on the function in order to retain economic consistency and so, we depict the assessable form and the econometric method.

### 5.2.2 General model

In its basic form, the cost function with a fixed factor is defined as a function of the prices  $P_i$  of each variable factor  $i$  and the level of the fixed factor called  $K$  thereafter:

$$Cv = f(P_i, K) \quad (5.1)$$

We can also write the unit cost of production as a function of the variable factor prices  $P_i$  and the level of the fixed factor  $K$ :

$$Cvu = \frac{C}{Y} = f_u(P_i, K) \quad (5.2)$$

The translog form of this unit cost function is defined as follows:

$$\begin{aligned} \log(Cvu) = & \alpha_0 + \sum_i \alpha_i \ln(P_i) + \alpha_K \ln(K) \\ & + \frac{1}{2} \sum_{i,j} \alpha_{ij} \ln(P_i) \ln(P_j) + \frac{1}{2} \alpha_{KK} \ln(K)^2 + \sum_i \alpha_{iK} \ln(P_i) \ln(K) \end{aligned} \quad (5.3)$$

In our model, for each of our four sectors under consideration, we consider non-ICT capital as the quasi-fixed factor and we keep intermediate consumption, high-skilled labor, low-skilled labor and ICT capital as variable factors. In addition, with respect to the previous form, in order to control the scale effects or any exogenous technical progress, we assume that the cost function also depends on the level of production and on time. Furthermore, we add externality variables in order to capture the effect of the widespread use of ICT in all sectors of the economy.

In our notation,  $K$  will refer to non-ICT capital,  $M$  to intermediate consumptions,  $HS$  and  $LS$  respectively to high-skilled and low-skilled labor,  $T$  to ICT-capital and  $P_i$  refers to the price of the factor  $i$ .  $Y$  represents gross output,  $t$  the time trend and  $\tilde{k}_T$  ICT externalities. In our model we define ICT externalities as an ICT capital index of the other sectors of the considered country. Thus, in this framework we can translate the previous basic general translog function to our case as follows:

$$Cv = f\left(P_{i=M,HS,LS,T}, K, Y, t, \tilde{k}_T\right) \quad (5.4)$$

$$Cvu = \frac{C}{Y} = f_u\left(P_i, K, Y, t, \tilde{k}_T\right) \quad (5.5)$$



$$\begin{aligned}
\ln(Cvu) &= \alpha_0 + \sum_i \alpha_i \ln(P_i) + \alpha_K \ln(K) \\
&+ \frac{1}{2} \sum_{i,j} \alpha_{ij} \ln(P_i) \ln(P_j) + \frac{1}{2} \alpha_{KK} \ln(K)^2 + \sum_i \alpha_{iK} \ln(P_i) \ln(K) \\
&+ \alpha_{ET} \ln(\tilde{k}_T) + \frac{1}{2} \alpha_{ETET} \ln(\tilde{k}_T)^2 + \sum_i \alpha_{iET} \ln(P_i) \ln(\tilde{k}_T) + c \sum_i \alpha_{KET} \ln(K) \ln(\tilde{k}_T) \\
&+ \alpha_Y \ln(Y) + \frac{1}{2} \alpha_{YY} \ln(Y)^2 + \sum_i \alpha_{iY} \ln(P_i) \ln(Y) + \alpha_{KY} \ln(K) \ln(Y) \\
&+ \alpha_{tt} t + \frac{1}{2} \alpha_{ttt} t^2 + \sum_i \alpha_{it} \ln(P_i) \times t + \alpha_{Kt} \ln(K) \times t \\
&+ \alpha_{Yt} \ln(Y) \times t + \alpha_{ETt} \ln(\tilde{k}_T) \times t + \alpha_{ETY} \ln(\tilde{k}_T) \ln(Y)
\end{aligned} \tag{5.6}$$

$i, j = HS, LS, M, T$

Where  $Cvu$  stands for the unit variable cost of production in the sector under consideration.

### 5.2.3 Estimation of the translog function

To be consistent with the economic theory, the specification should respect some features and thus we have to impose constraints on the parameters that we describe below. In particular, on one hand the function has to be homogeneous of degree one in price and, on the other hand, it must respect concavity constraints.

**Homogeneity constraints:** The homogeneity of degree one in price can be translated by the following constraints on parameters:

$$\begin{aligned}
\sum_{i=HS,LS,M,T} \alpha_i &= 1 \\
\sum_{j=HS,LS,M,T} \alpha_{ij} &= 0, \quad \forall i \in \{HS,LS,M,T\} \\
\sum_{i=HS,LS,M,T} \alpha_{iK} &= 0 \\
\sum_{i=HS,LS,M,T} \alpha_{iET} &= 0 \\
\sum_{i=HS,LS,M,T} \alpha_{iY} &= 0 \\
\sum_{i=HS,LS,M,T} \alpha_{it} &= 0
\end{aligned}$$

This set of conditions leads us to normalize the function by the price of one factor, we choose here to

normalize by the price of intermediate input but the factor chosen has no influence on the estimation results.

The application of these constraints resulted then in the following form:

$$\begin{aligned}
 \ln\left(\frac{Cvu}{P_M}\right) &= \alpha_0 + \sum_i \alpha_i \ln\left(\frac{P_i}{P_M}\right) + \alpha_K \ln\left(\frac{K}{Y}\right) \\
 &+ \frac{1}{2} \sum_{i,j} \alpha_{ij} \ln\left(\frac{P_i}{P_M}\right) \ln\left(\frac{P_j}{P_M}\right) + \frac{1}{2} \alpha_{KK} \ln\left(\frac{K}{Y}\right)^2 + \sum_i \alpha_{iK} \ln\left(\frac{P_i}{P_M}\right) \ln\left(\frac{K}{Y}\right) \\
 &+ \alpha_{ET} \ln(\tilde{k}_T) + \frac{1}{2} \alpha_{ETET} \ln(\tilde{k}_T)^2 + \sum_i \alpha_{iET} \ln\left(\frac{P_i}{P_M}\right) \ln(\tilde{k}_T) + \sum_i \alpha_{KET} \ln\left(\frac{K}{Y}\right) \ln(\tilde{k}_T) \\
 &+ \alpha_Y \ln(Y) + \frac{1}{2} \alpha_{YY} \ln(Y)^2 + \sum_i \alpha_{iY} \ln\left(\frac{P_i}{P_M}\right) \ln(Y) + \alpha_{KY} \ln\left(\frac{K}{Y}\right) \ln(Y) \\
 &+ \alpha_t t + \frac{1}{2} \alpha_{tt} t^2 + \sum_i \alpha_{it} \ln\left(\frac{P_i}{P_M}\right) \times t + \alpha_{Kt} \ln\left(\frac{K}{Y}\right) \times t \\
 &+ \alpha_{Yt} \ln(Y) \times t + \alpha_{ETt} \ln(\tilde{k}_T) \times t + \alpha_{ETtY} \ln(\tilde{k}_T) \ln(Y)
 \end{aligned} \tag{5.7}$$

$i, j = \text{HS, LS, T}$

From this equation we can deduce the short term shares in the variable cost for all variable factors as following:

For  $i = \text{HS, LS, T}$ :

$$\begin{aligned}
 S_{i,t} &= \frac{P_i X_i}{Cv} \\
 &= \frac{P_i}{Cv} \frac{\partial Cv}{\partial P_i} \\
 &= \frac{\partial \ln(Cv)}{\partial \ln(P_i)} \\
 &= \frac{\partial \ln(Cvu)}{\partial \ln\left(\frac{P_i}{P_M}\right)}
 \end{aligned}$$

Then

$$S_i = \alpha_i + \alpha_{ii} \ln\left(\frac{P_i}{P_M}\right) + \sum_{j=\text{HS,LS,T}} \alpha_{ij} \ln\left(\frac{P_j}{P_M}\right) + \alpha_{iK} \ln\left(\frac{K}{Y}\right) + \alpha_{ETi} \ln(\tilde{k}_T) + \alpha_{iY} \ln(Y) + \alpha_{it} t \tag{5.8}$$

We will deduce the share of intermediate consumption in the variable cost from the other shares:

$$S_M = 1 - S_{HS} - S_{LS} - S_T$$

**Concavity constraints:**

In the short run, we can impose or verify ex post that the cost function is characterized by diminishing returns with respect to the fixed factor using:

$$\alpha_{KK} + S_K (S_K - 1) > 0 \quad (5.9)$$

Where we note  $S_K = \frac{\partial \ln Cvu}{\partial \ln (K/Y)} < 0$  (see Devezeaux et al., 1989 [73] and Lau, 1976 [147])

In the long run, the concavity constraints are given in Brown and Christensen (1981, [34]). In practice these constraints are too heavy to be imposed, we verify ex post the concavity of the cost function.

**The final system:**

Finally we estimate the following final systems:

$$\left\{ \begin{array}{l}
 \ln\left(\frac{Cvu}{P_M}\right) = \alpha_0 + \sum_i \alpha_i \ln\left(\frac{P_i}{P_M}\right) + \alpha_K \ln\left(\frac{K}{Y}\right) \\
 \quad + \frac{1}{2} \sum_{i,j} \alpha_{ij} \ln\left(\frac{P_i}{P_M}\right) \ln\left(\frac{P_j}{P_M}\right) + \frac{1}{2} \alpha_{KK} \ln\left(\frac{K}{Y}\right)^2 + \sum_i \alpha_{iK} \ln\left(\frac{P_i}{P_M}\right) \ln\left(\frac{K}{Y}\right) \\
 \quad + \alpha_{ET} \ln(\tilde{k}_T) + \frac{1}{2} \alpha_{ETET} \ln(\tilde{k}_T)^2 + \sum_i \alpha_{iET} \ln\left(\frac{P_i}{P_M}\right) \ln(\tilde{k}_T) + \sum_i \alpha_{KET} \ln\left(\frac{K}{Y}\right) \ln(\tilde{k}_T) \\
 \quad + \alpha_Y \ln(Y) + \frac{1}{2} \alpha_{YY} \ln(Y)^2 + \sum_i \alpha_{iY} \ln\left(\frac{P_i}{P_M}\right) \ln(Y) + \alpha_{KY} \ln\left(\frac{K}{Y}\right) \ln(Y) \\
 \quad + \alpha_{it} + \frac{1}{2} \alpha_{itt^2} + \sum_i \alpha_{it} \ln\left(\frac{P_i}{P_M}\right) \times t + \alpha_{Kt} \ln\left(\frac{K}{Y}\right) \times t \\
 \quad + \alpha_{Yt} \ln(Y) \times t + \alpha_{ETt} \ln(\tilde{k}_T) \times t + \alpha_{ETY} \ln(\tilde{k}_T) \ln(Y) \\
 \\
 S_{HS} = \alpha_{HS} + \alpha_{HSHS} \ln\left(\frac{P_{HS}}{P_M}\right) + \alpha_{HSLs} \ln\left(\frac{P_{LS}}{P_M}\right) + \alpha_{HST} \ln\left(\frac{P_T}{P_M}\right) \\
 \quad + \alpha_{HSK} \ln\left(\frac{K}{Y}\right) + \alpha_{HSET} \ln(\tilde{k}_T) + \alpha_{HSY} \ln(Y) + \alpha_{HS} t \times t \\
 \\
 S_{LS} = \alpha_{LS} + \alpha_{LSLS} \ln\left(\frac{P_{LS}}{P_M}\right) + \alpha_{HSLs} \ln\left(\frac{P_{HS}}{P_M}\right) + \alpha_{LST} \ln\left(\frac{P_T}{P_M}\right) \\
 \quad + \alpha_{LSK} \ln\left(\frac{K}{Y}\right) + \alpha_{LSET} \ln(\tilde{k}_T) + \alpha_{LSY} \ln(Y) + \alpha_{LS} t \times t \\
 \\
 S_T = \alpha_T + \alpha_{TT} \ln\left(\frac{P_T}{P_M}\right) + \alpha_{HST} \ln\left(\frac{P_{HS}}{P_M}\right) + \alpha_{LST} \ln\left(\frac{P_{LS}}{P_M}\right) \\
 \quad + \alpha_{TK} \ln\left(\frac{K}{Y}\right) + \alpha_{TET} \ln(\tilde{k}_T) + \alpha_{TY} \ln(Y) + \alpha_{Tt} \times t
 \end{array} \right. \tag{5.10}$$

All variables, except the shares, are normalized (are equal to one) at the approximation point which is the year 1995 and we use the SUR (Seemingly Unrelated Regression), Zellner method for the estimation of this system.

### 5.3 Theoretical results

As written in the introduction, the adopted specification leads us to distinguish the short run and the long run equilibria. In the first one, we cannot adjust the non-ICT capital, but we can optimize the production only on the variable factors. In contrast, in the long term we can adjust the fixed capital to its optimum and then optimize with respect to all the production factors. In this section we formalise the relationship existing between the different inputs in both cases, many theoretical results

and demonstrations can be found in Devezeaux and Ladoux (1989, [73]).

### 5.3.1 Short run equilibrium

In the short term approach, non-ICT capital is considering as fixed, then decisions on the use of factors only relate to the variable factors that are high-skilled labor, low-skilled labor, intermediate consumption and ICT capital. So, in this part, we will characterise the short run equilibrium based on the prices of variable factors, the level of production, the time trend, the level of the ICT externalities and the fixed level of the non-ICT capital. More specifically, first we focus on the values of the different own-prices as well as substitution short run elasticities and, second, on the assessment of the short term impact of the widespread use of ICT throughout the economy on sectoral variable cost and on demand of factors for each studied sector.

#### 5.3.1.1 Elasticities

We determine three types of elasticities that have different advantages. The first type groups together the Allen elasticities which are noted  $\sigma_{ij}$  afterwards. These elasticities have the advantage of being symmetric so they provide a good idea of the complementarity or of the substitutability between two factors. However, these elasticities only give us qualitative information, as to obtain symmetry, the elasticities are divided by the share of the factor whose price is varies. Then quantitatively, the Allen elasticity will be greater as this share is small.

Consequently, in order to have good quantitative indications we use two other elasticities that we can deduce from those of Allen as described below. The first are the Marshall elasticities which are noted  $\epsilon_{ij}$  afterwards, and the latter are the Morishima elasticity which are noted  $\mu_{ij}$  here.

#### Short-run Allen elasticities

We obtain these externalities with the Uzawa formula:

For all variable factors  $i, j = \text{HS, LS, T, M}$

$$\sigma_{ii} = \frac{\alpha_{ii} + S_i(S_i - 1)}{S_i^2} \quad (5.11)$$

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \quad (5.12)$$

Marshall elasticities are given by:

$$\epsilon_{ij} = \frac{\partial \ln X_i}{\partial \ln P_j} = \sigma_{ij} \times W_j \quad (5.13)$$

Where  $X_i$  stands for the demand of the input  $i$ . This elasticity provides the relative variation in percentage of the demand for an input  $i$  when the price of an input  $j$  increases by 1%.

Morishima elasticities

$$\begin{aligned} \mu_{ij} &= \frac{\partial \ln \left( \frac{X_i}{X_j} \right)}{\partial \ln P_j} \\ &= \frac{\partial \ln X_i}{\partial \ln P_j} - \frac{\partial \ln X_j}{\partial \ln P_j} \end{aligned} \quad (5.14)$$

Then,

$$\mu_{ij} = \epsilon_{ij} - \epsilon_{jj} = (\sigma_{ij} - \sigma_{jj}) \times W_j \quad (5.15)$$

The Morishima elasticity is the log derivative of the input quantity ratio with respect to the input price ratio as it is defined in equation 5.14

### 5.3.1.2 Short run externalities

We assess the impact of the increase in the ICT capital intensity of the country, which is defined as the ratio of ICT capital with respect to the output level, on the short term variable cost, input shares in variable cost and input demands using the following equations:

$$\begin{aligned} \Xi_{Cvu} &= \frac{\partial \ln Cvu}{\partial \ln \tilde{k}_T} \\ &= \alpha_{ET} + \alpha_{ETET} \ln(\tilde{k}_T) + \sum_i \alpha_{iET} \ln\left(\frac{P_i}{P_M}\right) + \alpha_{KET} \ln\left(\frac{K}{Y}\right) + \alpha_{ETY} \ln(Y) + \alpha_{ETi}t \\ \Xi_{S_i} &= \frac{\partial \ln S_i}{\partial \ln \tilde{k}_T} = \frac{\alpha_{iET}}{S_i} \\ \Xi_{X_i} &= \frac{\partial \ln (\tilde{S}_i Cvu / P_i)}{\partial \ln \tilde{k}_T} = \Xi_{S_i} + \Xi_{Cvu} \end{aligned} \quad (5.16)$$

The first variable  $\Xi_{Cvu}$  is the relative variation of the unit variable cost when the country's ICT intensity increases by 1%. The second and the third respectively determine the relative variations of

the input shares in variable cost and of the input demand when the country's ICT intensity increases by 1% all things being equal (especially input prices).

### 5.3.2 Long run or K-optimum equilibrium

In the long term, non-ICT capital can be adjusted to its optimum, consequently the substitution possibilities being increased, the substitution elasticities are affected with respect to their short term value. Furthermore, ICT externalities can also influence the use of non-ICT capital. In this part, we will define the long run equilibrium according to the prices of all the variable factors and to the cost of use of the non-ICT capital in addition to the level of the production, the time and the level of the ICT externalities. In first step, we determine the optimum level of the non-ICT capital and we will also define a current capital ratio and marginal return from this capital that characterizes the gap between the current and the long run level of the non-ICT capital. Then, we establish the new measure of the own-price and substitution elasticities taking into account the adjustment of the non-ICT capital as well as the other variable inputs. Henceforth, we signal the long term values with an asterisk. The details of the calculus are given in appendix 2 (section 5.8 on page 196)

#### 5.3.2.1 The determination of the optimum level of Non-ICT capital (quasi-fixed capital)

The marginal productivity of non-ICT capital can be defined here as the reduction of the variable cost induced by an additional unit of capital. Moreover, at the optimum the marginal productivity of the capital must be equal to its user cost. Then, if production and all prices are fixed, we can write

$$\begin{aligned} P_K &= -Y \frac{dCvu}{dK} \\ &= -Y \frac{Cvu}{K} \frac{d \ln(Cvu)}{d \ln(K)} \\ &= -Y \frac{Cvu}{K} \frac{d \ln(Cvu)}{d \ln\left(\frac{K}{Y}\right)} \end{aligned}$$

This leads to the following equation that determines the optimum non-ICT capital:

$$\begin{aligned} \left(\frac{K}{Y}\right)^* &= -\frac{Cvu}{P_K} \left[ \alpha_K + \alpha_{KK} \ln\left(\frac{K}{Y}\right)^* + \alpha_{HSK} \ln\left(\frac{P_{HS}}{P_M}\right) + \alpha_{LSK} \ln\left(\frac{P_{LS}}{P_M}\right) \right. \\ &\quad \left. + \alpha_{TK} \ln\left(\frac{P_T}{P_M}\right) + \alpha_{KET} \ln(\tilde{k}_T) + \alpha_{KY} \ln(Y) + \alpha_{Kt} \times t \right] \end{aligned} \quad (5.17)$$

This equation cannot be solved analytically, we will therefore solve it in a numerical way.

We can also define the optimal share of the non-ICT capital in the variable cost (which is negative) as following:

$$\begin{aligned}
 S_K^* &= -\frac{P_K K^*}{Y C v u} \\
 &= \alpha_K + \alpha_{KK} \ln \left( \frac{K}{Y} \right)^* + \alpha_{HSK} \ln \left( \frac{P_{HS}}{P_M} \right) + \alpha_{LSK} \ln \left( \frac{P_{LS}}{P_M} \right) \\
 &\quad + \alpha_{TK} \ln \left( \frac{P_T}{P_M} \right) + \alpha_{KET} \ln \left( \tilde{k}_T \right) + \alpha_{KY} \ln (Y) + \alpha_{Kt} \times t
 \end{aligned} \tag{5.18}$$

### 5.3.2.2 The capital ratio and the marginal rate of return of the quasi-fixed non-ICT capital

As we know the optimum level of the use of non-ICT capital we can characterize the gap between this optimum level and the real current one by the following definition of a capital ratio corresponding to a use rate of the quasi-fixed factor and its marginal rate of return.

**The capital ratio of the quasi-fixed non-ICT capital:** The specification used here assumes that the real level of non-ICT capital is not adjusted to its optimal level because of the existence of rigidity on this capital in the short run. Then the use of this factor is non optimal if there are some exogeneous variations, especially in relative prices and outlets, in the short term. Therefore, we can identify the capital ratio of the capital to its distance from the optimum. For this point, we can refer to Berndt and Morrison (1981, [18]).

The capital ratio, defining the use rate of the quasi-fixed capital, is defined as the ratio between its optimum level and its real level<sup>4</sup> as in Devezeau and Ladoux [73]

$$u_{K,t} = \frac{K_t^*}{K_t} = \frac{(K/Y)_t^*}{(K/Y)_t} \tag{5.19}$$

In this way, if this ratio is less than 1, the real level of non-ICT capital is greater than the optimum one, then the capital is underutilized. Conversely, if the ratio is greater than 1, the level of the real non-ICT capital stock is less than the optimum one, so as the use of each unit of the real capital stock is more intensif than in the optimum case, then the capital is overused.

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<sup>4</sup>Here we do not use the traditional definition of the capacity utilization which is the percentage of actual output to potential output considering the actual level of capital.



**The marginal rate of return of the quasi-fixed non-ICT capital:** we define the marginal rate of return of the capital as the ratio between its marginal productivity and its user cost,  $P_K$ . So we can write here:

$$\rho_K = -Y \frac{\partial C_{vu}}{\partial K} \times \frac{1}{P_K} = -\frac{Y \times C_{vu}}{K \times P_K} \times S_K \quad (5.20)$$

Where we note

$$S_K = \alpha_K + \alpha_{KK} \ln\left(\frac{K}{Y}\right) + \alpha_{HSK} \ln\left(\frac{P_{HS}}{P_M}\right) + \alpha_{LSK} \ln\left(\frac{P_{LS}}{P_M}\right) \\ + \alpha_{TK} \ln\left(\frac{P_T}{P_M}\right) + \alpha_{KET} \ln(\tilde{k}_T) + \alpha_{KY} \ln(Y) + \alpha_{Kt} \times t$$

The partial derivative is obviously calculated at the point of the real level of the quasi-fixed capital, thus the rate of return of the capital is evaluated at its real level. In the long term, or at the optimal point, the rate of return of the capital must be equal, by definition, to the unity ( $\rho_{K^*} = 1$ ).

### 5.3.2.3 Long run elasticities

We obtain long run elasticities using the total differential of the cost function given that the level of the non-ICT capital is function to the prices, the level of production, the time and the level of the externalities. In the demonstration in the appendix (Appendix 5.8.2) we first calculate the Marshall elasticities and then we deduce those of Allen but, here, to keep the same order than in the short run equilibrium, we present the Allen elasticities first. Moreover, we note, to refer to the relationships (5.13) and (5.15), that the optimal shares  $W_i^*$  of the input  $i$  in the total cost can be written as follows, where we note  $S_i^*$  the optimal share in the variable cost of this input:

$$W_i^* = \frac{S_i^*}{1 + |S_K^*|} \quad (5.21)$$

The share of the non-ICT capital  $S_K^*$  as defined here is negative.

The long run value of the different long run run elasticities are given by the following formulas:

Allen elasticities

$$\begin{aligned}
 \sigma_{ii}^* &= \frac{1 + |S_K^*|}{S_i^{*2}} \left[ \alpha_{ii} + S_i^* (S_i^* - 1) - \frac{(S_i^* S_K^* + \alpha_{iK})^2}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \\
 \sigma_{ij}^* &= \frac{1 + |S_K^*|}{S_i^* S_j^*} \left[ \alpha_{ij} + S_i^* S_j^* - \frac{(S_i^* S_K^* + \alpha_{iK})(S_j^* S_K^* + \alpha_{jK})}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \\
 \sigma_{KK}^* &= \frac{1 + |S_K^*|}{S_K^* (S_K^* - 1) + \alpha_{KK}} \\
 \sigma_{iK}^* &= -\frac{1 + |S_K^*|}{S_i^*} \times \frac{S_i^* S_K^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}}
 \end{aligned} \tag{5.22}$$

Marshall elasticities

$$\begin{aligned}
 \epsilon_{ii}^* &= \frac{1}{S_i^*} \left[ \alpha_{ii} + S_i^* (S_i^* - 1) - \frac{(S_i^* S_K^* + \alpha_{iK})^2}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \\
 \epsilon_{ij}^* &= \frac{1}{S_i^*} \left[ \alpha_{ij} + S_i^* S_j^* - \frac{(S_i^* S_K^* + \alpha_{iK})(S_j^* S_K^* + \alpha_{jK})}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \\
 \epsilon_{KK}^* &= \frac{S_K^*}{S_K^* (S_K^* - 1) + \alpha_{KK}} \\
 \epsilon_{Ki}^* &= \frac{S_i^* S_K^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \\
 \epsilon_{iK}^* &= \frac{S_K^*}{S_i^*} \times \frac{S_i^* S_K^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}}
 \end{aligned} \tag{5.23}$$

Morishima elasticities We use the same equation as above (5.15)

### 5.3.2.4 Long run externalities

Finally, we can calculate the long term impact of the country's ICT intensity as follows:

$$\text{Noting } \xi_{ET}^* = \alpha_{ET} + \alpha_{ETET} \ln(\tilde{k}_T) + \sum_i \alpha_{iET} \ln\left(\frac{P_i}{P_M}\right) + \alpha_{KET} \ln\left(\frac{K^*}{Y}\right) + \alpha_{ETY} \ln(Y) + \alpha_{ET} t$$

$$\begin{aligned}
 \Xi_{Cvu}^* &= \frac{d \ln Cvu}{d \ln(\tilde{k}_T)} = \xi_{ET}^* - S_K^* \times \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \\
 \Xi_{S_i}^* &= \frac{d \ln S_i^*}{d \ln(\tilde{k}_T)} = \frac{1}{S_i^*} \left[ \alpha_{iET} - \alpha_{iK} \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \\
 \Xi_{X_i}^* &= \frac{d \ln X_i^*}{d \ln \tilde{k}_T} = \frac{S_i^* \xi_{ET}^* + \alpha_{iET}}{S_i^*} - \frac{[S_i^* S_K^* + \alpha_{iK}][S_K^* \xi_{ET}^* + \alpha_{KET}]}{S_i^* [S_K^* (S_K^* - 1) + \alpha_{KK}]} \\
 \Xi_K^* &= \frac{d \ln K^*}{d \ln(\tilde{k}_T)} = -\frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}}
 \end{aligned} \tag{5.24}$$

## 5.4 The data

For this study we use the EU KLEMS database that we have mentioned in previous chapters and we will briefly resume the main elements here. A more detailed description are available in Timmer and al. 2007 [216] and in O'Mahony and al. 2009 [176]. The building of this database has been financed by the European Commission and developed by a consortium coordinated by the Gröningen Growth and Development Center to analyse productivity in the European Union at the industry level. It includes measures of economic growth, productivity, employment creation per skill-age category, capital formation for different types of capital, notably ICT capital and it covers twenty five European countries, Japan, United-States and Australian for the period from 1970 to 2007 in the broader cases.

In truth, data from only twelve countries for the period from 1980 to 2005 have been exploited in this study because of the lack of complete data and time series in the other countries. So we use the data from nine European countries that are Austria, Belgium, Germany, Spain, Finland, France, Italy, the Netherlands and the United Kingdom and three other countries, Australia, Japan and United-States.

**Data on employment** In EU KLEMS the labour force is subdivided into several categories determined by various characteristics that are age (three age groups: 15-29, 30-49, 50 and over), gender (male and female) and educational attainment (three educational attainments: high, medium, low).

However, we have to take precautions in using these data to make comparaisons between countries. The last characteristic, educational attainment, is worth considering because, if the definition of high, medium and low educational levels are consistent over time for each country, it may differ accross countries due to the differences in educational systems even throughout Europe. Moreover, EU KLEMS “assume comparability only accross the bachelor degrees educational level (high), but not at the other levels.” We therefore distinguish only two types of educational attainment in our study given that we need to be able to compare countries. We use agreggate medium and low educational attainment in the low skill labour in our model.

Finally we do not separate the labour force with respect to the age or the gender and we only retain two categories of labour called high skilled labour (HS) and low skilled labour (LS) thereafter.

**Data on capital** In our study we distinguish two types of capital assets and one of the interests of EU KLEMS is that the details on capital assets allow us to make this distinction. The first category is defined as ICT capital which incorporates computing equipment, software and communication

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Table 5.3: Geometric depreciation rates used in EU KLEMS

EU KLEMS asset type	Minimum over industries	Maximum over industries
<b>Non-ICT assets</b>		
Residential structures	0.011	0.011
Non-residential structures	0.023	0.069
Infrastructure	0.023	0.069
Transport equipment	0.061	0.246
Other machinery and equipment	0.073	0.164
Products of agriculture and forestry	0.073	0.164
Other products	0.073	0.164
Other intangibles	0.315	0.315
<b>ICT assets</b>		
Computing equipment	0.315	0.315
Software	0.315	0.315
Communications equipment	0.115	0.115

*Source: M. Timmer and al., "EU KLEMS growth and productivity accounts", 2007 [216]*

equipment and the second group all the other non-ICT assets<sup>5</sup>.

For each of these capital categories, the database provides us with:

- The nominal gross fixed capital formation;
- The real gross fixed capital formation;
- The gross fixed capital formation price index;
- The real fixed capital stock;
- The capital compensation;
- The consumption of fixed capital.

In our model we assume that non-ICT capital is subject to rigidities that do not allow instantaneous adjustment and, for this reason, we defined it as a quasi-fixed factor, whereas we do not make such an assumption concerning ICT capital. This distinction between these two capital categories rests mainly on the differences in depreciation rates. Table 5.3 shows that depreciation rates are largely lower in average for non-ICT assets which means that the average lifetime of a unit of ICT capital is much lower and that it must be renewed much more frequently than other types of capital.

<sup>5</sup>Non-ICT capital includes: residential structures, non-residential structures, infrastructures, transport equipment, other machinery and equipment, products of agriculture and forestry and other intangibles of national accounts.

Furthermore, the price of the capital we use in our estimations is actually the cost of use of one capital unit which is equal to the capital compensation per unit of capital. This cost of use takes into account investment prices, depreciation rates and the interest rate.

As regards to the ICT input, we note here that it only includes ICT that are physically isolated and are not incorporated in production (ICT as intermediate consumption is not taken into account) as we discussed in chapter 3. We emphasized two sources of data inaccuracy. The first is in the identification of ICT assets. As Timmer and al. (2007 [216]) explain, “the definition of IT and CT assets have not been completely harmonised to date. In some countries IT has been defined broadly as office and computing equipment, whereas others have used the more narrowly defined category computers only.” So the definition of ICT is more or less broad depending on the country but further harmonization could not be done without detailed investment by product data. Secondly, the assumption that different vintages of each asset can be treated as perfect substitutes in production implies the measurement of investment in constant-quality efficiency units, so, “this requires constant-quality price indices for each asset type, in particular those which are subject to rapid technological change and improvements in quality, such as IT assets” (Timmer and al. 2007 [216]). Although most countries make quality adjustments, the authors follow previous comparative studies such as Colechia and Schreyer (2001) [52], Timmer and Van Ark (2005) [217] and Inklaar, O’Mahony and Timmer (2005) [124]. Furthermore they use the harmonisation procedure introduced by Schreyer (2002 [201]) for those countries for which IT deflators are clearly not adjusted for quality. So the ICT capital stock includes quality improvement (if a computer  $C_T$  of the period T is considered twice as efficient as a computer  $C_P$  of the periode P, the volume corresponding to the computer  $C_T$  is equal to twice the volume of the computer  $C_P$ ).

### 5.5 Estimation Results

We estimated the system (5.10) described above for four sectors: *Electrical and Optical Equipment; Transport Storage and Communication; Wholesale and Retail Trade* and *Finance, Insurance, Real Estate and Business Services*. As we explained in the introduction, we focus on these sectors because of their prominent role in recent economic growth and because of the strong dependencies between their growth and ICT diffusion. On one hand, the first sector, *Electrical and Optical Equipment*, which includes most ICT producing industries and the second which includes communication services industries, can be considered as producers of “information container and content” and, on the other hand, the

two other sectors are among the sectors where ICT diffusion has had the most impact. To have enough observation points, we proceeded in cross-country estimations and we add country specific parameters, thus we obtain 292 observation points. The joint estimation by Zellner method was performed on the shares in variable cost of high-skilled labor, low-skilled labor and ICT capital (respectively  $S_{HS}$ ,  $S_{LS}$ ,  $S_T$ ) and the unit cost function, imposing the constraints on parameters described in section 5.2. The details of the estimation results are given in table 5.5 in appendix 1 (section 5.7). From these estimation results, we performed the numerical resolution of the equation (5.17) allowing us to determine the long-run equilibrium for each sector.

**Deviation from the long term optimum** Figures 5.3 plot the utilization rate of the non-ICT capital in eight countries over the last twelve years of the sample. This utilization rate should be interpreted as follows. According to the definition given by the equation (5.19), when the rate is equal to 100%, the level of non-ICT capital is perfectly adjusted to its optimum level with respect to the market situation. If this rate is lower than 100% it means that the actual level of non-ICT capital is higher than the optimal level and consequently the use of each unit of capital is lower than if it were optimized. The sector's firms are thus encouraged to disinvest. Conversely, if this rate is above 100%, the actual level of non-ICT capital is lower than the optimal level and the firms in the sector are encouraged to invest more.

These graphs show that in the sector *Electrical and Optical Equipment*, countries diverge markedly after 1995 in terms of deviation from the optimum. Starting from an utilization rate between 80% and 90%, in some countries such as France or Germany the non-ICT capital becomes suboptimal over the period while it seems to become too high in Finland. Countries whose capital tends to adjust the most in this sector are US, Japan and Spain. In the sector *Wholesale and Retail Trade*, the non-ICT capital is generally under-optimal. Over the period, it tends to be more and more adjusted in the United Kingdom, in Italy, and in the United States and Germany until 2002-2003 but not in Finland, Japan and France, where the utilization rate seems to disclose under-investments in this sector over the whole period. Concerning the *Finance, Insurance, Real Estate and Business Services* industries, the United Kingdom shows a level of capital that is more optimized than in other countries, especially at the end of the period. The United States, Finland and France are the three other better adjusted countries for this sector, with an utilization rate between 85% and 90% since 2000. Thus, the global adjustment of the non-ICT capital to its optimal level since 1995 in the two ICT using services, *Wholesale and Retail*

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*Trade and Finance, Insurance, Real Estate and Business Services*, in most countries confirms the idea Gordon (2003 [92]) and Bosworth and Triplett (2007 [29]) put forward of a productivity growth based on profit-driven cost-cutting and the role of the flexibility of the economy by shifting of resources.

Figures 5.4 plot the ratio of the share of ICT capital in the short run variable cost to the level of this share if the non-ICT capital were adjusted for these same countries. Thus, according to these figures, if the ratio is higher than 1, the adjustment of the non-ICT capital tends to diminish the relative use of ICT, whereas if this ratio is lower than one, the adjustment of the quasi-fixed input will raise the relative use of ICT. Figures 5.3 and 5.4 are obviously closely related and the direction of variation of the first curve with respect to the second depends on the complementary or substitutability relationship between ICT and non-ICT capital. In fact, when the two inputs are complementary the two curves have opposite slopes and, conversely, when the two inputs are substitutable, like in the sector *Transport Storage and Communication* as we shall see afterwards, the two curves have slopes with the same sign. Nonetheless, in the sector *Wholesale and Retail Trade*, despite of the ICT - non ICT capital complementarity, the two curves vary in the same direction. This in fact reveals problems of non-concavity in the cost function<sup>6</sup>.

Then we globally observe that in United States the use of factors, and especially the level of the capital, is relatively better adjusted compared to most European countries in these four ICT producing or using industries. In Europe, the United Kingdom appears to be more optimized than US in ICT using services and especially in *Finance, Insurance, Real Estate and Business*. But France and Finland show misadjustment in *Wholesale and Retail Trade* and Germany rather in *Finance, Insurance, Real Estate and Business Services*. Japan show an adjusted capital only in “information container and content producing” industries (*Electrical and Optical Equipment* and *Transport and Communication*). Finally, the sensibility of the ICT capital share to the non-ICT capital adjustment seems to be more important in ICT intensive using industries and especially in *Finance, Insurance, Real Estate and Business Services* than in “information container and content” producing industries.

**Elasticities** Tables 5.6 (a) and (b) respectively give the short term and long term own price Marshall elasticities for ICT capital. The value of these elasticities is around -0.6 in average in the three ICT intensive using sectors. This means that the use of ICT capital increases by 0.6% when its cost of use

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<sup>6</sup>The strong significant negative parameter  $\alpha_{KK}$  leads to a positive long term own price elasticity for the non-ICT capital, which reflect non-concavity of the function in this sector. However imposing the concavity constraint prevents the convergence of the estimates.

Figure 5.3: Capital ratio of non-ICT capital

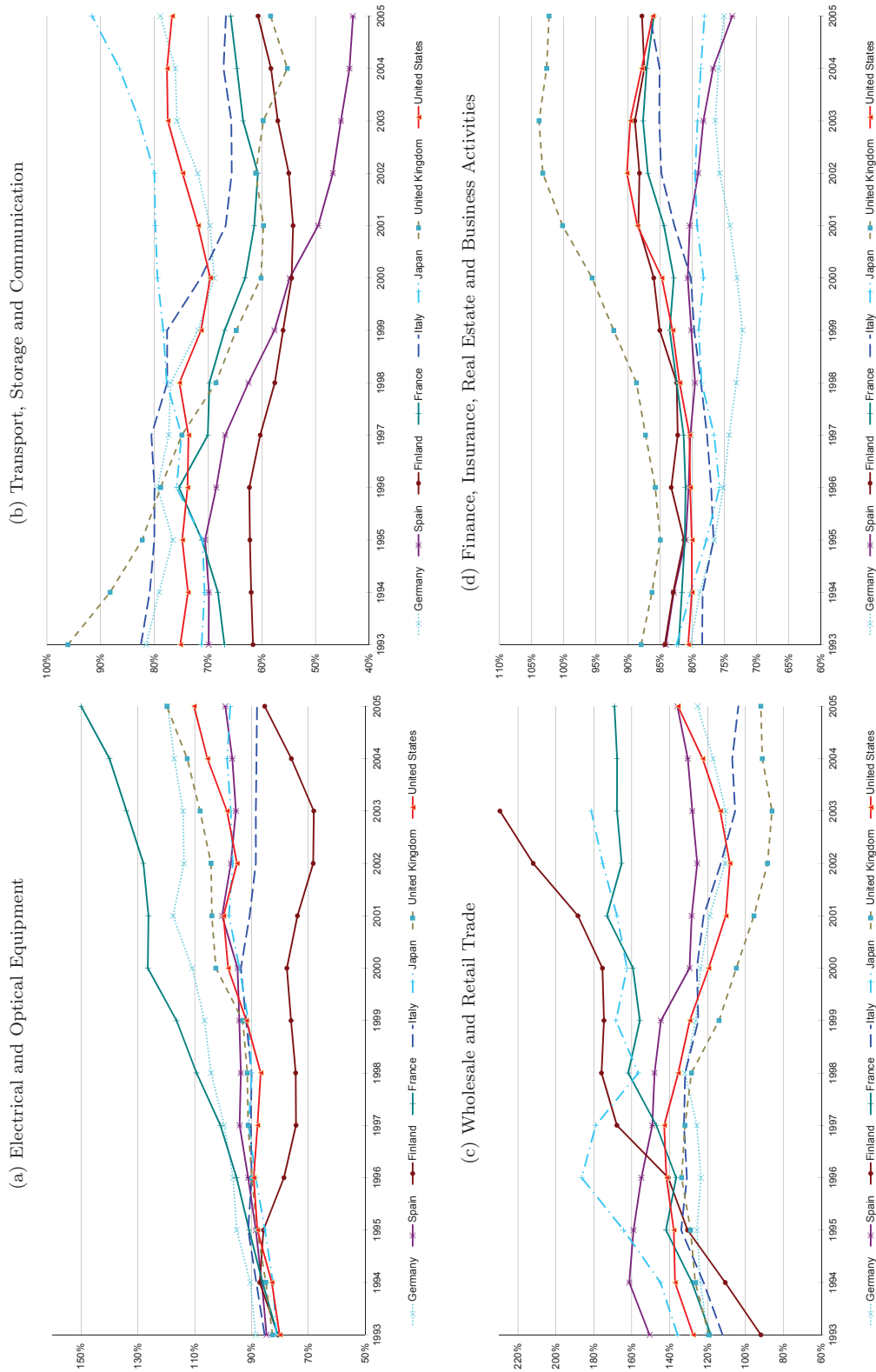
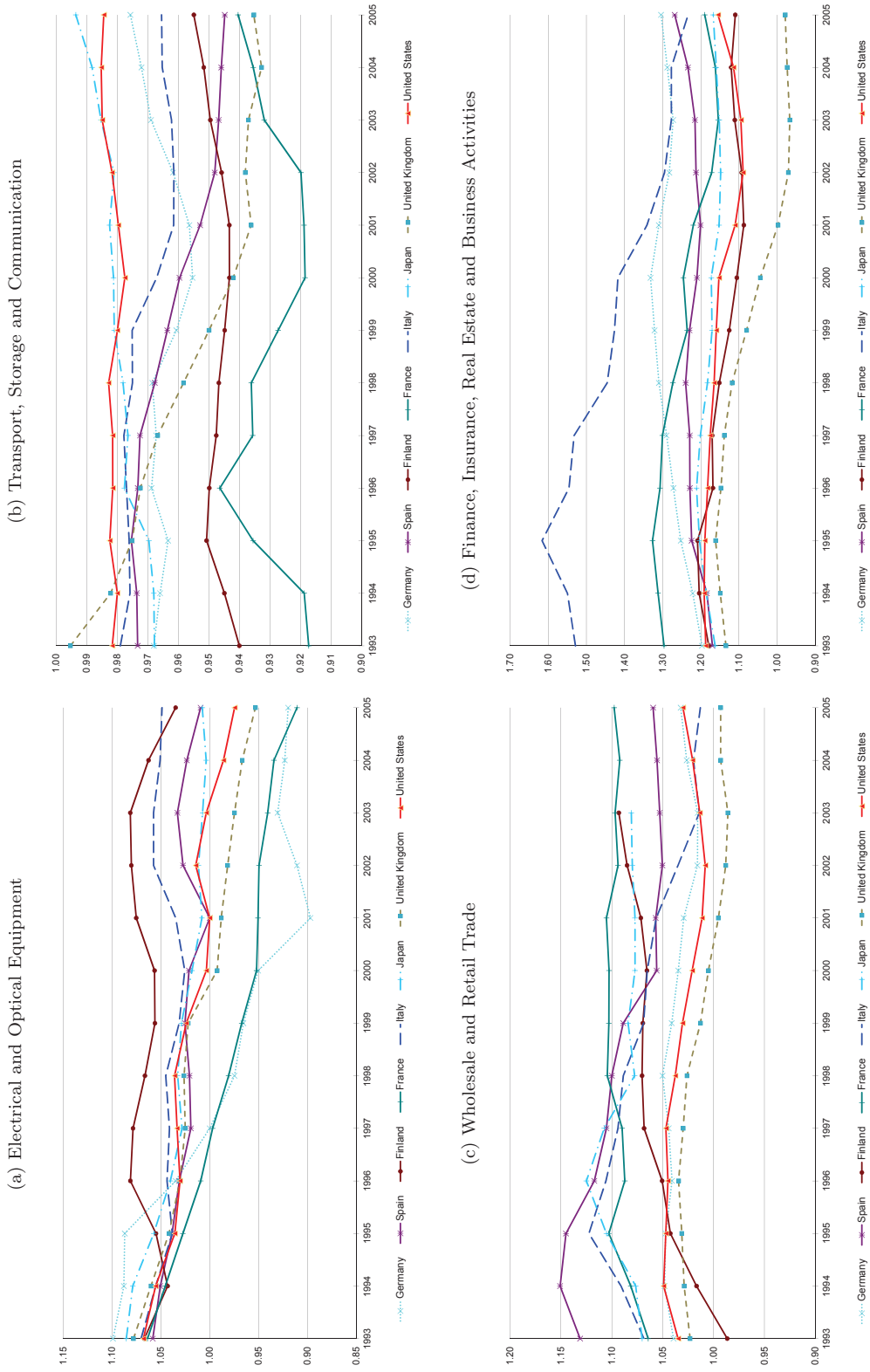




Figure 5.4: Ratio short term/Optimum ICT Capital share in variable cost



decreases by 1%. Short term elasticities depend on the coefficient  $\alpha_{TT}$  and on the ICT share in the variable cost, then given the great significance of the parameter, these elasticities are very significant. Moreover we observe that they are slightly smaller in the long run, except for *Transport Storage and Communication*. In fact, this is linked to the complementary relationship between ICT and non-ICT capital showed in table 5.8 with the negative sign of  $\sigma_{KT}$  for all sectors except *Transport Storage and Communication*. Notwithstanding, except in *Finance, Insurance, Real Estate and Business Services* where it decreases by almost 0.1 in average in the long run, these values do not suggest that these elasticities are significantly different in the long-term with respect to the short-term, and all the more in *Transport, Storage and Communication* as the coefficient  $\alpha_{TK}$  is not significant.

With regard to the substitution relationships between inputs, table 5.7 provides the short term Allen elasticities of substitution between variable inputs and table 5.8 provides the long run Allen elasticities between all inputs. Globally we find complementarity between ICT and non-ICT capital, except in *Transport Storage and Communication*. This complementarity between ICT and non-ICT capital means that ICT adoption may be affected by rigidities in other assets. In our model, even if the ICT capital is considered as a variable factor, the rigidities on quasi-fixed non ICT capital have all the more impact in that, in the short run, they constraint the use of variable inputs and thus of ICT. Indeed, we observe that the underuse of non-ICT capital has led to an overdemand for ICT capital with respect to the long term (see figure 5.4), especially in *Finance, Insurance, Real Estate and Business Services* which is the sector where the complementarity between ICT and non-ICT is the more significant.

Moreover, ICT capital seems to be weakly substitutable with high skilled labor in *Transport Storage and Communication* but relatively highly substitutable in *Wholesale and Retail Trade*. This latter sector is also the only one where ICT capital appears to be complementary with low skilled labor.

In *Wholesale and Retail Trade*, the value of the Hicks-Marshall elasticities  $\epsilon_{TM}$  in the short run (table 5.9), which are between 0.58 and 0.99, and all the more in the long run (table 5.10) since they are between 0.65 and 1.18, spotlight a high sensitivity of ICT to the price of intermediate consumption which should indicate that ICT are “intermediate consumption saving”. We could draw a parallel between this observation and some explanations on the post 2000 productivity growth based on cost-cutting and reallocation of material inputs like in Gordon (2003 [92]) or Bosworth and Triplett (2007 [29]). Indeed these strong elasticities could reflect the fact that ICT enable such “input saving” strategies. Furthermore, the higher level in Italy or Spain (more than 1 in the long run) could reflect

that these countries have not yet made the most of ICT's features in this sector.

Finally in the “information container and content” producing industries this ICT capital is, on the contrary, more complementary to intermediate consumption.

**Externalities** Tables 5.5 give us the estimated values of ICT spillovers. These spillovers are actually measured as the impact of the variation of ICT capital intensity, the latter being determined by the ratio ICT capital / output of the country excluding the considered sector. We note that the externality is positive when the sign of  $\Xi_{UVC}$  is negative since it represents the variation of production cost with respect to the increase in the ICT capital use. Furthermore, the short term impact of ICT externalities on variable cost corresponds to its relative first degree coefficient,  $\alpha_{ET}$  and thus, in fact, does not depend on the country (the values of  $\Xi_{UVC}$  are the same for all countries in tables 5.5 (a)).

We observe that, in the short run, the increase of ICT intensity in a country has a positive impact (a negative effect on the variable cost) in the sectors *Electrical and Optical Equipment* and *Finance, Insurance, Real Estate and Business Services* whereas it has significant negative impact on *Transport, Storage and Communication*. However, in *Wholesale and Retail Trade* the coefficient  $\alpha_{ET}$  is not significant for this sector, consequently we cannot deduce that ICT adoption in other sectors have significant impact on this sector. In the long run, the effects are the same as in the short run for *Electrical and Optical Equipment* and *Transport, Storage and Communication*, however the effects appear to be reversed for the other two sectors.

Concerning the demand of factors, the results show that in the short run as well as in the long run, the demand for ICT input is positively linked to its widespread diffusion in the four sectors and the parameter  $\alpha_{ETT}$  is significant in the four sectors (at 10% for *Transport, Storage and Communication* and at 1% for the other sectors). The effects on the demand of other inputs are more heterogenous between sectors. On high-skilled labor demand, the impact is significant only in *Wholesale and Retail Trade* and *Finance, Insurance, Real Estate and Business Services* and is negative in the first case but positive in the second. On low-skilled labor, the coefficient is relatively significant in all sectors but, once again, one is positive and the other negative. The externalities reduce the demand for low-skilled labor in *Electrical and Optical Equipment* and *Wholesale and Retail Trade*, but have no real impact in *Finance, Insurance, Real Estate and Business Services*<sup>7</sup>, and increase the low-skilled labor demand in *Transport, Storage and Communication*. Finally the impact of ICT adoption in other sectors is

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<sup>7</sup>It has no clear effect on low-skilled but it reduces the share of this input in variable cost

positive on intermediate input and negative on capital in *Transport, Storage and Communication* and in *Wholesale and Retail Trade* and this is the reverse in *Electrical and Optical Equipment* and *Finance, Insurance, Real Estate and Business Services*.

### 5.6 Conclusion

This chapter dealt with several issues concerning the behavior of ICT-producing and using industries, taking into account externalities induced by the widespread use of ICT as well as the rigidity of the production system, and we sum up the main results here.

We assess the ICT own price elasticity (the use of ICT capital with respect to its cost of use) around -0.6 for the intensive ICT using sectors and not far from -0.3 for *Electrical and Optical Equipment*, which is consistent with the elasticities found at the macro level that we will present in Chapter 8. Furthermore, this elasticity does not significantly change between the short and the long run except in *Finance, Insurance, Real Estate and Business Services* where it decreases by almost 0.1 in absolute value.

In addition, in the studied sectors we find a complementarity between ICT and non-ICT capital except for *Transport, Storage and Communication* and ICT capital seems to be highly substitutable with intermediate input and high-skilled labor in both ICT using industries, *Wholesale and Retail Trade* and *Finance, Insurance, Real Estate and Business Services*, whereas it is more a low-skilled labor substitute in “information container and content” producing sectors. These results are consistent and we must consider them with caution. In particular the specificity of the period, with the important growth between 1995 and 2000 following by the dotcom crisis, and the quality of data may bias the estimations. Further researches are necessary in this field.

Concerning the externalities, the increase of the national ICT intensity has a significant positive impact only on *Electrical and Optical Equipment* and *Finance, Insurance, Real Estate and Business Services* and is somewhat negative for the sector *Transport, Storage and Communication*. However, it tends systematically to increase demand for ICT which is in line with a horizontal externality of ICT use implying that firms are all the more motivated to use ICT if the number of users is large. To improve the consideration of externalities, we could incorporate international externalities, coming for example from the use of ICT in the same sector abroad, in a future study.

In other respects, the comparison of the long term and short term equilibriums shows that the

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share of ICT capital in variable cost is more sensitive to non-ICT capital rigidities in the ICT using industries, and especially in *Finance, Insurance, Real Estate and Business Services*, than in ICT producing industries. This observation is in fact consistent with the previous observation that ICT own price elasticity is impacted in the long run only in this sector. Thus cost optimization (or cost-cutting according to Gordon) seems to be particularly ICT related in such a sector.

The study made in this chapter sheds some light on the evolution of ICT-related industries in terms of optimization of production, however it is not sufficient to explain differences between countries and, in particular, non-ICT capital rigidities do not provide explanation of the productivity gap between the European countries.

In light of this study we must then look in other directions in order to clarify the role of ICT and, for this, this Gordon's assertion give us some indication:

“The extraordinary profit squeeze led in turn to savage cost cutting and layoffs, reducing labor input long after real GDP had begun to recover in late 2001. But, second, firms could not have maintained or increased output following the reduction in labor input without the help of both measured ICT investment and unmeasured complementary investments in intangible capital. Recent research shows that intangible capital that is complementary to computer hardware and software can cause measurement errors in official data on productivity, leading productivity growth to be understated in a period of buoyant ICT investment such as 1995-2000, and to be overstated in a period of slumping ICT investment such as 2000-02.” Gordon (2003 [92])

Therefore in the next part, after drawing up the framework of ICT as an enabling technology, we will address such issues, investigating first the impact of the intangible assets on productivity measurement and second the complementary between intangible and ICT investments.

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5.7 Appendix 1: Results and Tables

Table 5.4: Growth of Value Added and labor productivity per sector

(Annual average growth rate in % and percentage points; Calculus based on EU KLEMS)

Electrical and Optical Equipment												
	Growth rate of Value Added (1=2+3)				Output contribution from							
					Hours worked (2)				Labor productivity (3)			
	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005
Austria	2.3	4.4	-0.1	2.2	-2.8	-1.8	-1.9	-2.1	5.1	6.2	1.8	4.3
Belgium	-2.4	8.7	-4.0	0.8	-3.7	-0.8	-5.0	-3.2	1.3	9.6	1.0	3.9
Finland	11.4	25.8	9.2	15.5	3.8	6.3	-1.5	2.9	7.6	19.5	10.7	12.6
France	3.7	6.6	2.8	4.4	-2.1	0.2	-3.4	-1.8	5.9	6.5	6.2	6.2
Germany	-1.9	4.2	2.5	1.6	-5.2	-1.7	-2.0	-3.0	3.3	5.9	4.6	4.6
Italy	1.4	1.4	0.0	0.9	-2.6	0.3	0.3	-0.7	4.0	1.0	-0.3	1.6
Netherlands	2.1	7.6	-5.7	1.3	-4.2	-0.4	-3.6	-2.7	6.3	8.0	-2.1	4.1
Spain	2.3	2.9	-1.5	1.2	-4.0	3.5	-3.2	-1.2	6.3	-0.6	1.7	2.5
United Kingdom	2.9	7.5	-2.4	2.7	-4.3	1.1	-8.6	-3.9	7.1	6.4	6.2	6.6
Australia	6.4	1.3	2.4	3.4	-2.7	1.5	-3.1	-1.4	9.1	-0.2	5.5	4.8
Japan	5.0	8.2	6.9	6.7	-3.8	-1.4	-4.3	-3.2	8.8	9.6	11.2	9.9
United States	10.9	19.8	4.6	11.8	-2.0	1.2	-7.5	-2.8	12.9	18.6	12.1	14.6

Transport, Storage & Communication												
	Growth rate of Value Added (1=2+3)				Output contribution from							
					Hours worked (2)				Labor productivity (3)			
	1990-1995	1995-2200	2000-2005	1990-2005	1990-1995	1995-2200	2000-2005	1990-2005	1990-1995	1995-2200	2000-2005	1990-2005
Austria	2.7	2.6	1.5	2.2	0.5	0.7	-0.5	0.2	2.2	1.9	2.0	2.0
Belgium	1.5	2.2	1.8	1.8	-0.2	1.6	-1.0	0.1	1.7	0.6	2.8	1.7
Finland	1.3	6.9	3.3	3.8	-2.5	1.5	0.1	-0.3	3.8	5.4	3.2	4.1
France	2.5	6.6	3.6	4.2	-0.2	1.4	0.5	0.6	2.7	5.2	3.1	3.7
Germany	4.1	3.5	2.3	3.3	-2.0	-1.0	-1.0	-1.3	6.1	4.6	3.3	4.7
Italy	3.5	4.2	3.5	3.7	-0.8	1.5	1.2	0.6	4.3	2.7	2.3	3.1
Netherlands	3.0	7.8	3.7	4.8	1.9	2.7	-1.0	1.2	1.1	5.1	4.7	3.6
Spain	3.8	5.8	3.1	4.2	0.8	3.5	2.6	2.3	3.0	2.3	0.6	1.9
United Kingdom	3.5	8.7	3.1	5.1	-1.6	0.9	1.0	0.1	5.1	7.8	2.1	5.0
Australia	6.5	4.8	4.7	5.3	1.5	1.7	0.9	1.3	5.0	3.1	3.8	4.0
Japan	2.5	1.6	1.2	1.8	-0.2	-0.7	-1.4	-0.7	2.7	2.3	2.6	2.5
United States	4.6	4.5	3.5	4.2	1.8	2.4	-1.5	0.9	2.8	2.1	5.0	3.3

Wholesale & Retail Trade												
	Growth rate of Value Added (1=2+3)				Output contribution from							
					Hours worked (2)				Labor productivity (3)			
	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005
Austria	2.2	3.6	1.2	2.3	0.1	0.8	0.5	0.5	2.2	2.9	0.6	1.9
Belgium	0.4	-0.1	2.4	0.9	-0.8	0.2	0.9	0.1	1.2	-0.2	1.5	0.8
Finland	-4.9	4.3	4.7	1.3	-5.5	2.7	0.8	-0.7	0.6	1.6	3.9	2.0
France	1.6	2.6	0.9	1.7	-1.4	0.7	0.7	0.0	3.0	2.0	0.2	1.7
Germany	2.4	2.5	1.0	2.0	0.7	0.1	-1.1	-0.1	1.7	2.4	2.1	2.1
Italy	1.8	1.5	0.0	1.1	-1.7	0.2	-0.4	-0.6	3.5	1.3	0.3	1.7
Netherlands	2.4	6.1	2.2	3.6	2.3	1.4	-0.6	1.0	0.1	4.7	2.7	2.5
Spain	2.8	4.6	2.6	3.4	0.1	3.6	2.1	2.0	2.7	1.0	0.5	1.4
United Kingdom	2.3	3.1	3.8	3.1	-1.2	0.7	0.4	0.0	3.5	2.4	3.5	3.1
Australia	3.8	3.9	3.9	3.9	0.0	-0.1	2.2	0.7	3.8	4.0	1.7	3.2
Japan	5.1	0.5	0.1	1.9	-0.2	-1.5	-2.6	-1.4	5.3	2.0	2.7	3.4
United States	3.7	7.1	2.8	4.5	0.7	1.5	-0.5	0.6	2.9	5.6	3.3	3.9

Finance, Insurance, Real Estate & Business Services												
	Growth rate of Value Added (1=2+3)				Output contribution from							
					Hours worked (2)				Labor productivity (3)			
	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005	1990-1995	1995-2000	2000-2005	1990-2005
Austria	3.1	3.5	2.1	2.9	1.6	7.0	3.0	3.9	1.5	-3.5	-0.9	-1.0
Belgium	3.4	4.4	2.8	3.6	3.3	5.2	1.6	3.4	0.1	-0.8	1.2	0.2
Finland	0.3	3.4	1.0	1.6	-1.6	3.9	2.8	1.7	1.9	-0.5	-1.7	-0.1
France	0.9	3.5	2.2	2.2	0.6	3.3	1.3	1.7	0.3	0.2	0.9	0.5
Germany	4.9	3.1	1.1	3.0	3.8	4.2	1.4	3.1	1.1	-1.1	-0.3	-0.1
Italy	1.1	2.6	1.6	1.8	0.8	5.5	3.2	3.1	0.3	-2.9	-1.5	-1.4
Netherlands	4.0	5.2	1.2	3.5	4.2	5.5	-0.2	3.2	-0.2	-0.3	1.4	0.3
Spain	2.2	3.9	4.5	3.5	2.8	5.6	3.6	4.0	-0.6	-1.7	0.9	-0.5
United Kingdom	2.9	5.7	3.6	4.0	0.7	3.4	3.0	2.4	2.1	2.3	0.6	1.7
Australia	3.1	5.5	3.2	4.0	3.5	4.7	1.4	3.2	-0.3	0.8	1.8	0.8
Japan	3.3	2.2	2.5	2.7	0.7	1.4	1.2	1.1	2.6	0.8	1.3	1.6
United States	2.3	4.9	4.1	3.8	2.2	4.0	1.1	2.4	0.1	0.9	3.0	1.4

## 5.8 Appendix 2: Calculus and Demonstrations

### 5.8.1 Calculation of the marginal rate of return of quasi-fixed non-ICT capital

As explained above we define the rate of return on capital as the ratio between its marginal productivity and its user cost, so considering the production is fixed we can write here

$$\begin{aligned}
 \rho_K &= -Y \frac{\partial Cvu}{\partial K} \times \frac{1}{P_K} \\
 &= -\frac{Y \times Cvu}{Y \times Cvu} \frac{\partial \ln Cvu}{\partial \ln K} \\
 &= -\frac{K \times P_K}{Y \times Cvu} \frac{\partial \ln K}{\partial \ln Cvu} \\
 &= -\frac{K \times P_K}{Y \times Cvu} \frac{\partial \ln K/Y}{\partial \ln Cvu} \\
 &= -\frac{K \times P_K}{Y \times Cvu} S_K
 \end{aligned}$$

Where we note

$$\begin{aligned}
 S_K &= \alpha_K + \alpha_{KK} \ln \left( \frac{K}{Y} \right) + \alpha_{HSK} \ln \left( \frac{P_{HS}}{P_M} \right) + \alpha_{LSK} \ln \left( \frac{P_{LS}}{P_M} \right) \\
 &\quad + \alpha_{TK} \ln \left( \frac{P_T}{P_M} \right) + \alpha_{KET} \ln \left( \tilde{k}_T \right) + \alpha_{KY} \ln (Y) + \alpha_{Kt} \times t
 \end{aligned}$$

The partial derivative is calculated at the point of the real level of the quasi-fixed capital, thus the rate of return of the capital is evaluated at its real level. In the long term, or at the optimal point, the rate of return of the capital must be equal, by definition, to the unity ( $\rho_{K^*} = 1$ ).

### 5.8.2 Calculation of long term price elasticities

The own price elasticities of non-ICT capital

$$\begin{aligned}
 \frac{\partial P_K}{\partial K} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial K} \\
 \frac{\partial P_K}{\partial K} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial K} \\
 &= -Y \frac{\frac{\partial Cvu}{\partial K} \frac{d \ln Cvu}{d \ln K/Y}}{\partial K} \\
 &= -Y \left\{ -\frac{Cvu}{K^2} \frac{d \ln Cvu}{d \ln \frac{K}{Y}} + \frac{K}{K^2} \left[ \frac{d \ln Cvu}{d \ln \frac{K}{Y}} \times \frac{Cvu}{K} \times \frac{d \ln Cvu}{d \ln K} \right] + \frac{d}{dK} \left( \frac{d \ln Cvu}{d \ln \frac{K}{Y}} \right) \times Cvu \right\} \\
 &= -Y \left\{ -\frac{Cvu}{K^2} + \frac{Cvu}{K^2} \left[ \left( \frac{d \ln Cvu}{d \ln \frac{K}{Y}} \right)^2 + \alpha_{KK} \right] \right\} \\
 &= \frac{YCvu}{K^2} \left\{ -\left( -\frac{P_K K}{YCvu} \right) + \left( -\frac{P_K K}{YCvu} \right)^2 + \alpha_{KK} \right\} \\
 &= -\frac{YCvu}{K^2} \{ S_K^* (S_K^* - 1) + \alpha_{KK} \} \\
 &= \frac{P_K}{K} \left( \frac{S_K^* (S_K^* - 1) + \alpha_{KK}}{S_K^*} \right)
 \end{aligned}$$

Then we have

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Table 5.5: Estimation Results (292 observations; significance level: \*.10%, \*\*.5%, \*\*\*.1%)

<i>Electrical and Optical Equipment (30t33)</i>			<i>Wholesale and Retail Trade (G)</i>			<i>Transport and Storage and Communication (I)</i>			<i>Finance, Insurance, Real Estate and Business Services (JtK)</i>						
Equation		R <sup>2</sup>	Equation		R <sup>2</sup>	Equation		R <sup>2</sup>	Equation		R <sup>2</sup>				
Coef. Value	Std. Error	Sign. Level	Coef. Value	Std. Error	Sign. Level	Coef. Value	Std. Error	Sign. Level	Coef. Value	Std. Error	Sign. Level				
$\alpha_H$	0.010	0.824	$\alpha_H$	-0.243	0.030	***	$\alpha_H$	0.033	0.025	$\alpha_H$	0.155	0.025	***		
$\alpha_L$	-0.016	0.053	$\alpha_L$	0.494	0.033	***	$\alpha_L$	0.258	0.036	$\alpha_L$	0.113	0.022	***		
$\alpha_T$	-0.050	0.011	***	$\alpha_T$	-0.012	0.005	**	$\alpha_T$	0.068	0.009	***	$\alpha_T$	-0.025	0.007	***
$\alpha_K$	0.011	0.032	***	$\alpha_K$	0.099	0.027	***	$\alpha_K$	0.046	0.026	*	$\alpha_K$	0.145	0.041	***
$\alpha_{HH}$	0.037	0.007	***	$\alpha_{HH}$	0.034	0.007	***	$\alpha_{HH}$	0.030	0.004	***	$\alpha_{HH}$	0.049	0.008	***
$\alpha_{LL}$	0.097	0.010	***	$\alpha_{LL}$	0.141	0.017	***	$\alpha_{LL}$	0.175	0.012	***	$\alpha_{LL}$	0.204	0.013	***
$\alpha_{TT}$	0.018	0.001	***	$\alpha_{TT}$	0.006	0.001	***	$\alpha_{TT}$	0.013	0.002	***	$\alpha_{TT}$	0.020	0.001	***
$\alpha_{KK}$	0.814	0.272	***	$\alpha_{KK}$	-0.993	0.211	***	$\alpha_{KK}$	0.524	0.373	*	$\alpha_{KK}$	2.486	0.471	***
$\alpha_{HL}$	0.005	0.008	***	$\alpha_{HL}$	-0.013	0.008	*	$\alpha_{HL}$	-0.010	0.005	*	$\alpha_{HL}$	-0.083	0.007	***
$\alpha_{HT}$	0.001	0.001	***	$\alpha_{HT}$	0.006	0.001	***	$\alpha_{HT}$	-0.001	0.001	***	$\alpha_{HT}$	0.001	0.002	***
$\alpha_{LT}$	0.000	0.002	***	$\alpha_{LT}$	-0.017	0.002	***	$\alpha_{LT}$	0.022	0.003	***	$\alpha_{LT}$	-0.011	0.002	***
$\alpha_{HK}$	0.020	0.004	***	$\alpha_{HK}$	0.026	0.004	***	$\alpha_{HK}$	0.002	0.005	***	$\alpha_{HK}$	0.067	0.009	***
$\alpha_{LK}$	0.067	0.008	***	$\alpha_{LK}$	0.035	0.012	***	$\alpha_{LK}$	0.021	0.012	*	$\alpha_{LK}$	-0.061	0.015	***
$\alpha_{TK}$	0.008	0.002	***	$\alpha_{TK}$	-0.004	0.002	*	$\alpha_{TK}$	-0.006	0.007	***	$\alpha_{TK}$	0.046	0.005	***
$\alpha_t$	0.002	0.003	***	$\alpha_t$	-0.008	0.002	***	$\alpha_t$	-0.017	0.002	***	$\alpha_t$	-0.001	0.002	***
$\alpha_{tt}$	-0.005	0.001	***	$\alpha_{tt}$	-0.002	0.001	***	$\alpha_{tt}$	0.000	0.001	***	$\alpha_{tt}$	-0.004	0.001	***
$\alpha_{Ht}$	0.000	0.000	***	$\alpha_{Ht}$	0.001	0.000	***	$\alpha_{Ht}$	0.002	0.000	***	$\alpha_{Ht}$	0.002	0.000	***
$\alpha_{Lt}$	-0.006	0.001	***	$\alpha_{Lt}$	-0.004	0.001	***	$\alpha_{Lt}$	0.000	0.001	***	$\alpha_{Lt}$	-0.002	0.001	***
$\alpha_{Tt}$	0.000	0.000	***	$\alpha_{Tt}$	0.001	0.000	***	$\alpha_{Tt}$	0.003	0.000	***	$\alpha_{Tt}$	0.001	0.000	***
$\alpha_{Kt}$	-0.021	0.008	**	$\alpha_{Kt}$	0.050	0.011	***	$\alpha_{Kt}$	-0.052	0.013	***	$\alpha_{Kt}$	-0.022	0.013	*
$\alpha_Y$	-0.121	0.026	***	$\alpha_Y$	0.002	0.032	***	$\alpha_Y$	-0.027	0.037	***	$\alpha_Y$	0.260	0.051	***
$\alpha_{YY}$	0.653	0.167	***	$\alpha_{YY}$	-0.045	0.384	***	$\alpha_{YY}$	0.876	0.303	***	$\alpha_{YY}$	2.028	0.426	***
$\alpha_{HY}$	-0.005	0.003	***	$\alpha_{HY}$	-0.007	0.007	***	$\alpha_{HY}$	-0.023	0.006	***	$\alpha_{HY}$	0.088	0.012	***
$\alpha_{LY}$	-0.012	0.006	**	$\alpha_{LY}$	-0.058	0.019	***	$\alpha_{LY}$	-0.173	0.015	***	$\alpha_{LY}$	-0.135	0.019	***
$\alpha_{TY}$	-0.002	0.002	***	$\alpha_{TY}$	0.000	0.003	***	$\alpha_{TY}$	-0.026	0.009	***	$\alpha_{TY}$	0.028	0.007	***
$\alpha_{KY}$	0.523	0.184	***	$\alpha_{KY}$	-0.372	0.279	***	$\alpha_{KY}$	1.361	0.274	***	$\alpha_{KY}$	3.314	0.380	***
$\alpha_{ET}$	-0.052	0.030	*	$\alpha_{ET}$	0.007	0.023	***	$\alpha_{ET}$	0.121	0.019	***	$\alpha_{ET}$	-0.042	0.017	**
$\alpha_{ETET}$	-0.597	0.184	***	$\alpha_{ETET}$	-0.354	0.134	***	$\alpha_{ETET}$	0.102	0.081	***	$\alpha_{ETET}$	-0.405	0.110	***
$\alpha_{ETH}$	0.002	0.003	***	$\alpha_{ETH}$	0.012	0.003	***	$\alpha_{ETH}$	-0.003	0.002	***	$\alpha_{ETH}$	-0.015	0.004	***
$\alpha_{ETL}$	-0.009	0.006	*	$\alpha_{ETL}$	-0.030	0.008	***	$\alpha_{ETL}$	-0.009	0.005	**	$\alpha_{ETL}$	0.011	0.006	*
$\alpha_{ETT}$	0.016	0.002	***	$\alpha_{ETT}$	0.007	0.001	***	$\alpha_{ETT}$	-0.005	0.003	*	$\alpha_{ETT}$	0.010	0.002	***
$\alpha_{ETK}$	-0.051	0.121	***	$\alpha_{ETK}$	-0.557	0.114	***	$\alpha_{ETK}$	0.040	0.093	***	$\alpha_{ETK}$	-1.041	0.150	***
$\alpha_{ETt}$	0.064	0.016	***	$\alpha_{ETt}$	0.026	0.012	**	$\alpha_{ETt}$	0.001	0.010	***	$\alpha_{ETt}$	0.042	0.010	***
$\alpha_{ETY}$	-0.360	0.079	***	$\alpha_{ETY}$	0.085	0.127	***	$\alpha_{ETY}$	-0.225	0.108	**	$\alpha_{ETY}$	-0.530	0.200	***



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Table 5.6: Own-Price ICT Elasticities

(a) Short Term ICT Marshall Own-Price Elasticities ( $\epsilon_{TT}$ )

Sectors	Countries											
	AT	AU	BE	DE	ES	FI	FR	IT	JP	NL	UK	US
<i>Electrical &amp; Optical Equipment</i>	--	-0.03	-0.54	--	-0.31	-0.19	-0.36	-0.03	-0.22	-0.03	-0.25	-0.36
<i>Trans. &amp; Stor. &amp; Communication</i>	-0.76	-0.65	-0.67	-0.64	-0.76	-0.70	-0.51	-0.69	-0.73	-0.70	-0.67	-0.76
<i>Wholesale &amp; Retail Trade</i>	-0.69	-0.74	-0.76	-0.67	-0.58	-0.74	-0.56	-0.42	-0.68	-0.68	-0.78	-0.75
<i>Fin., Ins., Real Est. &amp; Business</i>	-0.42	-0.43	-0.51	-0.62	-0.57	-0.58	-0.45	-0.36	-0.64	-0.45	-0.58	-0.63

(b) Long Term ICT Marshall Own-Price Elasticities ( $\epsilon_{TT}^*$ )

Sectors	Countries											
	AT	AU	BE	DE	ES	FI	FR	IT	JP	NL	UK	US
<i>Electrical &amp; Optical Equipment</i>	--	0.00	-0.53	--	-0.28	-0.15	-0.36	0.00	-0.19	-0.02	-0.23	-0.33
<i>Trans. &amp; Stor. &amp; Communication</i>	-0.77	-0.68	-0.69	-0.66	-0.77	-0.72	-0.55	-0.71	-0.75	-0.72	-0.68	-0.77
<i>Wholesale &amp; Retail Trade</i>	-0.66	-0.74	-0.76	-0.66	-0.52	-0.74	-0.54	-0.38	-0.65	-0.68	-0.78	-0.75
<i>Fin., Ins., Real Est. &amp; Business</i>	-0.24	-0.28	-0.42	-0.54	-0.50	-0.52	-0.30	0.01	-0.59	-0.34	-0.53	-0.58

Table 5.7: Short Term Allen Elasticities of Substitution ( $\sigma_{ij}$ )

<i>Electrical &amp; Optical Equipment</i>						
	$\sigma_{HLS}$	$\sigma_{HST}$	$\sigma_{LST}$	$\sigma_{HSM}$	$\sigma_{LSM}$	$\sigma_{TM}$
AT	1.53	2.68	0.96	-1.28	0.51	-1.63
AU	1.41	1.68	0.97	-0.52	0.46	-0.50
BE	1.34	1.24	0.99	-0.28	0.42	0.31
DE	1.26	2.54	0.90	-0.03	0.46	-4.35
ES	1.42	1.32	0.97	0.07	0.25	0.06
FI	1.51	1.33	0.95	0.23	0.04	-0.05
FR	1.52	1.44	0.98	-0.43	0.36	0.11
IT	2.06	2.62	0.97	-2.41	0.45	-0.39
JP	1.34	1.30	0.97	0.21	0.26	-0.10
NL	2.09	2.38	0.96	-1.72	0.38	-0.32
UK	1.52	1.55	0.97	-0.54	0.40	-0.07
US	1.20	1.13	0.97	0.56	0.08	0.04

<i>Transport &amp; Storage &amp; Communication</i>						
	$\sigma_{HLS}$	$\sigma_{HST}$	$\sigma_{LST}$	$\sigma_{HSM}$	$\sigma_{LSM}$	$\sigma_{TM}$
AT	-0.11	0.30	1.56	-1.14	0.05	0.17
AU	-0.18	-0.05	2.69	-0.13	0.01	-0.25
BE	-0.32	-0.03	2.57	-0.21	-0.01	-0.12
DE	-0.36	-0.58	2.42	-0.80	0.11	-0.45
ES	0.42	0.73	1.90	0.39	-0.13	0.28
FI	0.71	0.77	2.21	0.61	-0.09	-0.23
FR	0.56	0.16	2.82	0.25	0.11	-1.36
IT	-0.79	-0.60	2.15	-1.30	0.09	-0.14
JP	0.57	0.65	1.77	0.20	0.03	-0.12
NL	-0.59	-0.37	2.13	-1.03	0.08	-0.10
UK	0.47	0.39	2.14	0.10	0.09	-0.48
US	0.69	0.87	1.76	0.62	-0.24	0.28

<i>Wholesale &amp; Retail Trade</i>						
	$\sigma_{HLS}$	$\sigma_{HST}$	$\sigma_{LST}$	$\sigma_{HSM}$	$\sigma_{LSM}$	$\sigma_{TM}$
AT	0.13	10.11	-0.74	-0.77	0.50	1.45
AU	-0.02	8.10	-0.63	-0.54	0.48	1.31
BE	0.18	5.16	-0.90	0.12	0.41	1.26
DE	0.29	10.21	-0.61	-0.96	0.50	1.56
ES	0.52	7.43	-1.67	0.14	0.47	1.60
FI	0.75	2.61	-0.85	0.61	0.33	1.37
FR	0.41	9.73	-1.72	-0.11	0.49	1.64
IT	-1.00	37.86	-2.86	-2.12	0.52	1.76
JP	0.80	2.71	-1.26	0.64	0.30	1.51
NL	-0.85	22.03	-0.71	-2.99	0.52	1.47
UK	0.26	5.54	-0.26	-0.29	0.47	1.28
US	0.80	2.35	-0.52	0.59	0.32	1.40

<i>Fin., Ins., Real Estate &amp; Business</i>						
	$\sigma_{HLS}$	$\sigma_{HST}$	$\sigma_{LST}$	$\sigma_{HSM}$	$\sigma_{LSM}$	$\sigma_{TM}$
AT	-1.53	1.19	0.12	1.63	0.38	0.50
AU	-1.31	1.13	-0.12	1.42	0.25	0.54
BE	-2.13	1.14	0.05	1.53	0.27	0.64
DE	-2.68	1.15	0.43	1.81	0.36	0.72
ES	-1.01	1.07	0.10	1.34	0.10	0.66
FI	-1.39	1.06	-0.20	1.27	-0.18	0.69
FR	-1.15	1.12	-0.05	1.41	0.24	0.55
IT	-1.16	1.21	0.16	1.71	0.41	0.37
JP	-0.81	1.05	0.32	1.33	0.06	0.72
NL	-1.85	1.18	0.10	1.62	0.36	0.55
UK	-1.25	1.08	0.12	1.37	0.13	0.68
US	-0.89	1.04	0.01	1.25	-0.28	0.70

Table 5.8: Long Term Allen Elasticities of Substitution ( $\sigma_{ij}^*$ )

<i>Electrical &amp; Optical Equipment</i>												
	$\sigma_{HLS}^*$	$\sigma_{HST}^*$	$\sigma_{LST}^*$	$\sigma_{HSM}^*$	$\sigma_{LSM}^*$	$\sigma_{TM}^*$	$\sigma_{HMS}^*$	$\sigma_{KLS}^*$	$\sigma_{RT}^*$	$\sigma_{MM}^*$		
AT	1.61	4.48	0.98	-1.37	0.58	-1.92	-0.76	-0.15	-0.85	0.28		
AU	1.44	2.29	1.00	-0.49	0.53	-0.54	-0.49	-0.20	-0.44	0.26		
BE	1.37	1.51	1.04	0.25	0.49	0.34	-0.38	-0.21	-0.15	0.26		
DE	1.23	3.88	0.62	0.02	0.51	-5.28	-0.34	-0.24	-2.08	0.22		
ES	1.50	1.71	1.01	0.11	0.32	0.06	-0.28	-0.34	-0.26	0.26		
FI	1.65	1.79	0.99	0.28	0.09	-0.06	-0.20	-0.49	-0.30	0.28		
FR	1.53	1.85	1.01	-0.41	0.43	0.14	-0.51	-0.28	-0.25	0.24		
IT	2.05	4.14	0.98	-2.68	0.52	-0.42	-1.42	-0.23	-0.45	0.24		
JP	1.48	1.74	1.05	0.27	0.33	-0.11	-0.18	-0.29	-0.28	0.30		
NL	1.89	3.34	0.90	-1.77	0.43	-0.31	-1.18	-0.34	-0.49	0.19		
UK	1.61	2.18	1.04	-0.58	0.47	-0.08	-0.53	-0.23	-0.29	0.27		
US	1.31	1.35	1.02	0.62	0.14	0.03	-0.05	-0.38	-0.23	0.28		

<i>Transport &amp; Storage &amp; Communication</i>												
	$\sigma_{HLS}^*$	$\sigma_{HST}^*$	$\sigma_{LST}^*$	$\sigma_{HSM}^*$	$\sigma_{LSM}^*$	$\sigma_{TM}^*$	$\sigma_{HMS}^*$	$\sigma_{KLS}^*$	$\sigma_{RT}^*$	$\sigma_{MM}^*$		
AT	-0.22	0.48	1.70	-1.23	0.05	0.18	-0.01	0.08	0.28	0.23		
AU	-0.36	0.17	2.98	-0.18	-0.03	-0.26	0.12	0.12	0.46	0.29		
BE	-0.50	0.18	2.84	-0.25	-0.04	-0.13	0.06	0.08	0.41	0.25		
DE	-0.52	-0.26	2.58	-0.88	0.11	-0.45	-0.03	0.06	0.40	0.22		
ES	0.41	0.86	2.14	0.43	-0.18	0.29	0.17	0.11	0.35	0.28		
FI	0.78	0.90	2.56	0.68	-0.17	-0.29	0.29	0.22	0.48	0.37		
FR	0.57	0.36	3.04	0.26	0.10	-1.41	0.16	0.14	0.55	0.28		
IT	-0.98	-0.26	2.28	-1.36	0.09	-0.13	-0.12	0.02	0.32	0.18		
JP	0.60	0.78	1.97	0.21	0.01	-0.14	0.16	0.14	0.37	0.29		
NL	-0.81	-0.10	2.34	-1.14	0.07	-0.12	-0.01	0.10	0.38	0.25		
UK	0.47	0.55	2.23	0.13	0.09	-0.47	0.02	0.01	0.33	0.16		
US	0.74	0.97	1.95	0.68	-0.29	0.30	0.15	0.06	0.29	0.24		

<i>Finance, Insurance, Real Estate and Business Services</i>												
	$\sigma_{HLS}^*$	$\sigma_{HST}^*$	$\sigma_{LST}^*$	$\sigma_{HSM}^*$	$\sigma_{LSM}^*$	$\sigma_{TM}^*$	$\sigma_{HMS}^*$	$\sigma_{KLS}^*$	$\sigma_{RT}^*$	$\sigma_{MM}^*$		
AT	-2.51	1.79	0.10	2.52	0.45	0.74	-0.18	0.27	-0.60	0.23		
AU	-1.84	1.58	-0.25	1.97	0.28	0.76	-0.09	0.25	-0.59	0.19		
BE	-3.07	1.54	0.05	2.18	0.31	0.90	-0.18	0.25	-0.43	0.19		
DE	-5.26	1.95	0.61	3.31	0.42	1.09	-0.32	0.33	-0.20	0.28		
ES	-1.46	1.56	0.12	1.88	0.09	0.95	-0.01	0.29	-0.31	0.22		
FI	-1.87	1.53	-0.30	1.75	-0.25	0.98	0.02	0.33	-0.29	0.21		
FR	-1.69	1.65	-0.16	2.01	0.27	0.79	-0.06	0.27	-0.55	0.21		
IT	-2.24	2.20	0.02	2.90	0.50	0.47	-0.15	0.31	-0.84	0.29		
JP	-1.29	1.64	0.44	1.98	0.02	1.06	0.05	0.33	-0.16	0.27		
NL	-2.61	1.49	0.11	2.25	0.42	0.76	-0.24	0.21	-0.54	0.17		
UK	-1.61	1.38	0.18	1.78	0.15	0.89	-0.08	0.23	-0.33	0.16		
US	-1.24	1.54	-0.01	1.74	-0.39	1.01	0.06	0.34	-0.21	0.23		

<i>Wholesale &amp; Retail Trade</i>												
	$\sigma_{HLS}^*$	$\sigma_{HST}^*$	$\sigma_{LST}^*$	$\sigma_{HSM}^*$	$\sigma_{LSM}^*$	$\sigma_{TM}^*$	$\sigma_{HMS}^*$	$\sigma_{KLS}^*$	$\sigma_{RT}^*$	$\sigma_{MM}^*$		
AT	0.36	10.37	-0.48	-0.73	1.23	3.16	0.58	-1.04	-1.91	-1.67		
AU	0.16	7.72	-0.72	-0.50	0.60	1.74	0.70	-0.13	-0.50	-0.42		
BE	0.35	5.43	-0.99	0.18	0.58	1.82	0.35	-0.22	-0.66	-0.58		
DE	0.40	9.77	-0.71	-0.95	0.57	1.98	0.70	-0.08	-0.45	-0.36		
ES	0.84	9.57	-2.18	0.37	1.00	3.32	-0.05	-0.77	-1.81	-1.31		
FI	0.89	2.91	-0.92	0.72	0.41	1.79	0.00	-0.10	-0.47	-0.42		
FR	0.58	10.38	-2.07	-0.07	0.72	2.57	0.35	-0.31	-0.99	-0.67		
IT	-0.53	31.15	-3.62	-1.72	0.66	2.57	1.42	-0.17	-0.93	-0.46		
JP	1.39	4.20	-1.29	1.34	0.91	3.30	-0.81	-0.95	-1.90	-1.68		
NL	-0.45	17.39	-0.80	-2.51	0.63	1.92	1.57	-0.12	-0.51	-0.40		
UK	0.39	5.46	-0.27	-0.28	0.57	1.62	0.54	-0.10	-0.39	-0.38		
US	1.01	2.79	-0.54	0.78	0.45	2.00	-0.12	-0.22	-0.61	-0.61		

CHAPTER 5. FACTORS DEMAND IN ICT-RELATED INDUSTRIES

Table 5.9: Short Term Marshall Elasticities of Substitution ( $\epsilon_{ij}$ )

<b>Electrical &amp; Optical Equipment</b>												
	$\epsilon_{HSLs}$	$\epsilon_{LSHS}$	$\epsilon_{HST}$	$\epsilon_{THS}$	$\epsilon_{LST}$	$\epsilon_{TLS}$	$\epsilon_{HSM}$	$\epsilon_{MHS}$	$\epsilon_{LSM}$	$\epsilon_{MLS}$	$\epsilon_{TM}$	$\epsilon_{MT}$
AT	0.50	0.05	0.03	0.08	0.01	0.31	-0.81	-0.04	0.32	0.17	-1.03	-0.02
AU	0.41	0.06	0.03	0.07	0.02	0.28	-0.34	-0.02	0.30	0.13	-0.33	-0.01
BE	0.38	0.07	0.05	0.07	0.04	0.28	-0.18	-0.02	0.26	0.12	0.20	0.01
DE	0.38	0.08	0.01	0.17	0.00	0.27	-0.02	0.00	0.29	0.14	-2.74	-0.02
ES	0.27	0.09	0.04	0.08	0.03	0.18	0.05	0.00	0.18	0.05	0.04	0.00
FI	0.21	0.11	0.03	0.10	0.02	0.13	0.18	0.02	0.03	0.01	-0.04	0.00
FR	0.35	0.07	0.04	0.06	0.03	0.22	-0.30	-0.02	0.25	0.08	0.08	0.00
IT	0.55	0.04	0.05	0.05	0.02	0.26	-1.67	-0.04	0.32	0.12	-0.27	-0.01
JP	0.26	0.10	0.03	0.10	0.02	0.19	0.15	0.02	0.18	0.05	-0.07	0.00
NL	0.46	0.04	0.04	0.05	0.02	0.21	-1.27	-0.04	0.28	0.08	-0.24	-0.01
UK	0.37	0.06	0.04	0.06	0.02	0.24	-0.37	-0.02	0.28	0.10	-0.05	0.00
US	0.20	0.18	0.03	0.17	0.03	0.16	0.36	0.08	0.06	0.01	0.03	0.00

<b>Transport &amp; Storage &amp; Communication</b>												
	$\epsilon_{HSLs}$	$\epsilon_{LSHS}$	$\epsilon_{HST}$	$\epsilon_{THS}$	$\epsilon_{LST}$	$\epsilon_{TLS}$	$\epsilon_{HSM}$	$\epsilon_{MHS}$	$\epsilon_{LSM}$	$\epsilon_{MLS}$	$\epsilon_{TM}$	$\epsilon_{MT}$
AT	-0.05	0.00	0.03	0.01	0.14	0.68	-0.52	-0.02	0.02	0.02	0.08	0.02
AU	-0.05	0.00	0.00	0.00	0.12	0.81	-0.08	0.00	0.00	0.00	-0.16	-0.01
BE	-0.09	-0.01	0.00	0.00	0.12	0.75	-0.14	-0.01	-0.01	0.00	-0.07	-0.01
DE	-0.13	-0.01	-0.02	-0.01	0.10	0.90	-0.45	-0.02	0.06	0.04	-0.26	-0.02
ES	0.12	0.02	0.06	0.04	0.16	0.56	0.22	0.02	-0.07	-0.04	0.16	0.02
FI	0.24	0.07	0.04	0.07	0.12	0.74	0.31	0.06	-0.05	-0.03	-0.12	-0.01
FR	0.23	0.03	0.00	0.01	0.08	1.18	0.12	0.01	0.05	0.04	-0.68	-0.04
IT	-0.29	-0.01	-0.03	-0.01	0.11	0.78	-0.74	-0.02	0.05	0.03	-0.08	-0.01
JP	0.24	0.03	0.04	0.03	0.12	0.75	0.09	0.01	0.01	0.01	-0.05	-0.01
NL	-0.21	-0.01	-0.02	-0.01	0.12	0.76	-0.59	-0.02	0.05	0.03	-0.06	-0.01
UK	0.19	0.02	0.02	0.02	0.10	0.89	0.05	0.00	0.04	0.04	-0.24	-0.02
US	0.21	0.07	0.08	0.09	0.17	0.53	0.31	0.06	-0.12	-0.07	0.14	0.03

<b>Wholesale &amp; Retail Trade</b>												
	$\epsilon_{HSLs}$	$\epsilon_{LSHS}$	$\epsilon_{HST}$	$\epsilon_{THS}$	$\epsilon_{LST}$	$\epsilon_{TLS}$	$\epsilon_{HSM}$	$\epsilon_{MHS}$	$\epsilon_{LSM}$	$\epsilon_{MLS}$	$\epsilon_{TM}$	$\epsilon_{MT}$
AT	0.06	0.00	0.22	0.33	-0.02	-0.34	-0.37	-0.02	0.25	0.23	0.70	0.03
AU	-0.01	0.00	0.22	0.26	-0.02	-0.24	-0.30	-0.02	0.27	0.19	0.72	0.04
BE	0.05	0.01	0.15	0.26	-0.03	-0.27	0.07	0.01	0.25	0.12	0.77	0.04
DE	0.15	0.01	0.21	0.35	-0.01	-0.32	-0.40	-0.03	0.21	0.26	0.65	0.03
ES	0.22	0.03	0.11	0.47	-0.03	-0.70	0.07	0.01	0.24	0.20	0.81	0.02
FI	0.26	0.11	0.07	0.39	-0.02	-0.30	0.29	0.09	0.16	0.12	0.65	0.04
FR	0.18	0.02	0.14	0.49	-0.03	-0.75	-0.05	-0.01	0.25	0.21	0.82	0.02
IT	-0.41	-0.02	0.41	0.60	-0.03	-1.17	-1.19	-0.03	0.29	0.21	0.99	0.02
JP	0.29	0.14	0.06	0.48	-0.03	-0.46	0.28	0.11	0.13	0.11	0.66	0.03
NL	-0.41	-0.01	0.46	0.32	-0.01	-0.34	-1.44	-0.04	0.25	0.25	0.71	0.03
UK	0.11	0.01	0.18	0.23	-0.01	-0.11	-0.15	-0.01	0.24	0.20	0.65	0.04
US	0.32	0.13	0.07	0.38	-0.01	-0.21	0.24	0.10	0.13	0.13	0.58	0.04

<b>Fin., Ins., Real Estate &amp; Business</b>												
	$\epsilon_{HSLs}$	$\epsilon_{LSHS}$	$\epsilon_{HST}$	$\epsilon_{THS}$	$\epsilon_{LST}$	$\epsilon_{TLS}$	$\epsilon_{HSM}$	$\epsilon_{MHS}$	$\epsilon_{LSM}$	$\epsilon_{MLS}$	$\epsilon_{TM}$	$\epsilon_{MT}$
AT	-0.51	-0.15	0.04	0.12	0.00	0.04	0.87	0.16	0.20	0.13	0.27	0.02
AU	-0.34	-0.18	0.04	0.16	0.00	-0.03	0.80	0.20	0.14	0.06	0.31	0.02
BE	-0.54	-0.22	0.05	0.12	0.00	0.01	0.91	0.16	0.16	0.07	0.38	0.03
DE	-0.83	-0.20	0.07	0.08	0.03	0.13	1.01	0.13	0.20	0.11	0.40	0.04
ES	-0.23	-0.18	0.06	0.19	0.01	0.02	0.72	0.24	0.05	0.02	0.36	0.03
FI	-0.23	-0.30	0.06	0.23	-0.01	-0.03	0.72	0.27	-0.10	-0.03	0.39	0.04
FR	-0.30	-0.17	0.04	0.16	0.00	-0.01	0.78	0.21	0.13	0.06	0.30	0.02
IT	-0.46	-0.11	0.04	0.12	0.01	0.06	0.81	0.17	0.20	0.16	0.18	0.01
JP	-0.19	-0.16	0.07	0.21	0.02	0.07	0.67	0.26	0.03	0.01	0.36	0.05
NL	-0.57	-0.18	0.05	0.11	0.00	0.03	0.91	0.15	0.20	0.11	0.31	0.02
UK	-0.28	-0.20	0.06	0.17	0.01	0.03	0.76	0.22	0.07	0.03	0.38	0.04
US	-0.15	-0.23	0.07	0.27	0.00	0.00	0.63	0.32	-0.14	-0.05	0.36	0.04

Table 5.10: Long Term Marshall Elasticities of Substitution ( $\epsilon_{ij}^*$ )

		<i>Electrical &amp; Optical Equipment</i>																		
	$\epsilon_{HLS}^*$	$\epsilon_{LSHS}^*$	$\epsilon_{HST}^*$	$\epsilon_{THS}^*$	$\epsilon_{LST}^*$	$\epsilon_{TLS}^*$	$\epsilon_{HSM}^*$	$\epsilon_{MHS}^*$	$\epsilon_{LSM}^*$	$\epsilon_{MLS}^*$	$\epsilon_{TM}^*$	$\epsilon_{MT}^*$	$\epsilon_{KHS}^*$	$\epsilon_{HSK}^*$	$\epsilon_{KLS}^*$	$\epsilon_{LSK}^*$	$\epsilon_{KT}^*$	$\epsilon^{*TK}$	$\epsilon^{*KM}$	$\epsilon^{*MK}$
AT	0.47	0.04	0.04	0.11	0.01	0.29	-0.81	-0.03	0.34	0.17	-1.13	-0.02	-0.02	-0.06	-0.04	-0.01	-0.01	-0.07	0.17	0.02
AU	0.38	0.06	0.04	0.09	0.02	0.26	-0.30	-0.02	0.32	0.14	-0.33	-0.01	-0.02	-0.03	-0.05	-0.01	-0.01	-0.03	0.16	0.02
BE	0.35	0.07	0.06	0.07	0.04	0.27	-0.15	-0.01	0.29	0.12	0.20	0.01	-0.02	-0.02	-0.05	-0.01	-0.01	-0.01	0.16	0.02
DE	0.35	0.08	0.02	0.25	0.00	0.18	0.01	0.00	0.32	0.15	-3.26	-0.02	-0.02	-0.01	-0.07	-0.01	-0.01	-0.06	0.13	0.01
ES	0.25	0.08	0.04	0.10	0.02	0.17	0.07	0.01	0.22	0.05	0.04	0.00	-0.02	-0.02	-0.06	-0.03	-0.01	-0.02	0.18	0.02
FI	0.19	0.10	0.04	0.11	0.02	0.11	0.20	0.02	0.06	0.01	-0.04	0.00	-0.01	-0.02	-0.06	-0.05	-0.01	-0.03	0.20	0.03
FR	0.32	0.06	0.05	0.07	0.03	0.21	-0.27	-0.02	0.29	0.09	0.09	0.00	-0.02	-0.03	-0.06	-0.02	-0.01	-0.02	0.16	0.02
IT	0.50	0.03	0.07	0.06	0.02	0.24	-1.77	-0.04	0.34	0.13	-0.28	-0.01	-0.02	-0.09	-0.06	-0.01	-0.01	-0.03	0.16	0.01
JP	0.24	0.10	0.04	0.12	0.02	0.17	0.17	0.02	0.21	0.05	-0.07	0.00	-0.01	-0.02	-0.05	-0.03	-0.01	-0.03	0.19	0.03
NL	0.40	0.04	0.06	0.06	0.02	0.19	-1.27	-0.03	0.31	0.09	-0.22	-0.01	-0.02	-0.04	-0.07	-0.01	-0.01	-0.01	0.14	0.01
UK	0.35	0.06	0.05	0.07	0.02	0.23	-0.37	-0.02	0.30	0.10	-0.05	0.00	-0.02	-0.04	-0.05	-0.02	-0.01	-0.02	0.17	0.02
US	0.19	0.18	0.03	0.18	0.03	0.15	0.38	0.08	0.09	0.02	0.02	0.00	-0.01	0.00	-0.06	-0.03	-0.01	-0.02	0.17	0.02

		<i>Transport &amp; Storage &amp; Communication</i>																		
	$\epsilon_{HLS}^*$	$\epsilon_{LSHS}^*$	$\epsilon_{HST}^*$	$\epsilon_{THS}^*$	$\epsilon_{LST}^*$	$\epsilon_{TLS}^*$	$\epsilon_{HSM}^*$	$\epsilon_{MHS}^*$	$\epsilon_{LSM}^*$	$\epsilon_{MLS}^*$	$\epsilon_{TM}^*$	$\epsilon_{MT}^*$	$\epsilon_{KHS}^*$	$\epsilon_{HSK}^*$	$\epsilon_{KLS}^*$	$\epsilon_{LSK}^*$	$\epsilon_{KT}^*$	$\epsilon^{*TK}$	$\epsilon^{*KM}$	$\epsilon^{*MK}$
AT	-0.09	0.00	0.04	0.01	0.14	0.66	-0.52	-0.02	0.02	0.02	0.07	0.01	0.00	0.00	0.03	0.01	0.02	0.02	0.10	0.02
AU	-0.09	-0.01	0.01	0.00	0.12	0.76	-0.10	0.00	-0.02	-0.01	-0.14	-0.01	0.00	0.02	0.03	0.02	0.02	0.06	0.16	0.04
BE	-0.13	-0.01	0.01	0.00	0.13	0.72	-0.14	-0.01	-0.02	-0.01	-0.07	-0.01	0.00	0.01	0.02	0.01	0.02	0.04	0.14	0.03
DE	-0.17	-0.01	-0.01	0.00	0.10	0.87	-0.46	-0.01	0.06	0.04	-0.24	-0.02	0.00	0.00	0.02	0.01	0.02	0.03	0.11	0.02
ES	0.10	0.02	0.06	0.04	0.16	0.54	0.22	0.02	-0.09	-0.04	0.15	0.02	0.01	0.02	0.03	0.01	0.03	0.04	0.14	0.03
FI	0.21	0.06	0.04	0.07	0.12	0.69	0.30	0.06	-0.08	-0.05	-0.13	-0.01	0.02	0.05	0.06	0.04	0.02	0.08	0.16	0.06
FR	0.21	0.03	0.01	0.02	0.08	1.10	0.12	0.01	0.04	0.03	-0.63	-0.04	0.01	0.02	0.05	0.02	0.01	0.06	0.12	0.03
IT	-0.33	-0.01	-0.01	0.00	0.12	0.76	-0.73	-0.02	0.05	0.03	-0.07	-0.01	0.00	-0.01	0.01	0.00	0.02	0.02	0.10	0.01
JP	0.22	0.03	0.05	0.04	0.12	0.73	0.09	0.01	0.00	0.00	-0.06	-0.01	0.01	0.02	0.05	0.02	0.02	0.04	0.12	0.03
NL	-0.26	-0.01	-0.01	0.00	0.12	0.74	-0.59	-0.02	0.04	0.02	-0.06	-0.01	0.00	0.00	0.03	0.01	0.02	0.04	0.13	0.03
UK	0.18	0.02	0.03	0.02	0.10	0.87	0.06	0.01	0.04	0.03	-0.22	-0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.08	0.01
US	0.20	0.07	0.08	0.09	0.17	0.52	0.31	0.06	-0.13	-0.08	0.13	0.03	0.01	0.01	0.02	0.01	0.03	0.03	0.11	0.02

CHAPTER 5. FACTORS DEMAND IN ICT-RELATED INDUSTRIES

<i>Wholesale &amp; Retail Trade</i>																			
	$\epsilon^{*}_{HSLS}$	$\epsilon^{*}_{LHS}$	$\epsilon^{*}_{HST}$	$\epsilon^{*}_{THS}$	$\epsilon^{*}_{LST}$	$\epsilon^{*}_{TLS}$	$\epsilon^{*}_{HSM}$	$\epsilon^{*}_{MHS}$	$\epsilon^{*}_{LSM}$	$\epsilon^{*}_{MLS}$	$\epsilon^{*}_{TM}$	$\epsilon^{*}_{MT}$	$\epsilon^{*}_{KHS}$	$\epsilon^{*}_{HSK}$	$\epsilon^{*}_{KLS}$	$\epsilon^{*}_{LSK}$	$\epsilon^{*}_{KT}$	$\epsilon^{*}_{TK}$	$\epsilon^{*}_{MK}$
AT	0.12	0.01	0.15	0.33	-0.01	-0.16	-0.24	-0.02	0.40	0.42	1.04	0.05	0.02	0.16	-0.35	-0.30	-0.03	-0.54	-0.48
AU	0.05	0.01	0.17	0.26	-0.02	-0.24	-0.23	-0.02	0.27	0.20	0.79	0.04	0.02	0.11	-0.04	-0.02	-0.01	-0.07	-0.19
BE	0.09	0.02	0.13	0.26	-0.02	-0.25	0.09	0.01	0.28	0.15	0.87	0.04	0.02	0.07	-0.06	-0.04	-0.02	-0.13	-0.11
DE	0.19	0.01	0.17	0.35	-0.01	-0.34	-0.34	-0.03	0.20	0.27	0.71	0.03	0.02	0.08	-0.04	-0.01	-0.01	-0.05	-0.04
ES	0.27	0.05	0.09	0.54	-0.02	-0.70	0.13	0.02	0.35	0.32	1.16	0.03	0.00	-0.01	-0.24	-0.20	-0.02	-0.48	-0.35
FI	0.28	0.12	0.06	0.39	-0.02	-0.29	0.28	0.10	0.16	0.13	0.70	0.04	0.00	0.00	-0.03	-0.01	-0.01	-0.07	-0.06
FR	0.21	0.03	0.11	0.49	-0.02	-0.74	-0.03	0.00	0.28	0.26	0.99	0.03	0.02	0.07	-0.11	-0.06	-0.01	-0.20	-0.13
IT	-0.19	-0.01	0.26	0.62	-0.03	-1.27	-0.79	-0.03	0.31	0.23	1.18	0.02	0.03	0.23	-0.06	-0.03	-0.01	-0.15	-0.07
JP	0.38	0.19	0.06	0.57	-0.02	-0.35	0.39	0.18	0.27	0.25	0.97	0.04	-0.11	-0.23	-0.26	-0.27	-0.03	-0.54	-0.47
NL	-0.19	-0.01	0.30	0.31	-0.01	-0.34	-1.01	-0.04	0.26	0.27	0.78	0.03	0.03	0.21	-0.05	-0.02	-0.01	-0.07	-0.05
UK	0.14	0.02	0.15	0.23	-0.01	-0.10	-0.12	-0.01	0.25	0.21	0.70	0.04	0.02	0.07	-0.04	-0.01	-0.01	-0.05	-0.05
US	0.34	0.14	0.06	0.39	-0.01	-0.18	0.25	0.11	0.15	0.15	0.65	0.05	-0.02	-0.02	-0.07	-0.04	-0.01	-0.11	-0.20

<i>Fin., Ins., Real Estate &amp; Business</i>																			
	$\epsilon^{*}_{HSLS}$	$\epsilon^{*}_{LHS}$	$\epsilon^{*}_{HST}$	$\epsilon^{*}_{THS}$	$\epsilon^{*}_{LST}$	$\epsilon^{*}_{TLS}$	$\epsilon^{*}_{HSM}$	$\epsilon^{*}_{MHS}$	$\epsilon^{*}_{LSM}$	$\epsilon^{*}_{MLS}$	$\epsilon^{*}_{TM}$	$\epsilon^{*}_{MT}$	$\epsilon^{*}_{KHS}$	$\epsilon^{*}_{HSK}$	$\epsilon^{*}_{KLS}$	$\epsilon^{*}_{LSK}$	$\epsilon^{*}_{KT}$	$\epsilon^{*}_{TK}$	$\epsilon^{*}_{MK}$
AT	-0.62	-0.15	0.03	0.11	0.00	0.03	0.97	0.15	0.17	0.11	0.29	0.01	-0.01	-0.05	0.07	0.08	-0.01	-0.17	0.09
AU	-0.38	-0.18	0.03	0.15	-0.01	-0.05	0.85	0.19	0.12	0.06	0.33	0.02	-0.01	-0.02	0.05	0.06	-0.01	-0.15	0.08
BE	-0.61	-0.21	0.04	0.11	0.00	0.01	1.00	0.15	0.14	0.06	0.41	0.02	-0.01	-0.04	0.05	0.06	-0.01	-0.10	0.09
DE	-1.13	-0.19	0.06	0.07	0.02	0.13	1.24	0.12	0.16	0.09	0.41	0.04	-0.01	-0.11	0.07	0.11	-0.01	-0.07	0.11
ES	-0.25	-0.18	0.05	0.19	0.00	0.02	0.75	0.23	0.04	0.02	0.38	0.03	0.00	0.00	0.05	0.08	-0.01	-0.09	0.06
FI	-0.24	-0.27	0.05	0.22	-0.01	-0.04	0.74	0.26	-0.11	-0.03	0.42	0.03	0.00	0.00	0.04	0.09	-0.01	-0.08	0.09
FR	-0.34	-0.16	0.04	0.16	0.00	-0.03	0.82	0.19	0.11	0.06	0.32	0.02	-0.01	-0.02	0.05	0.07	-0.01	-0.15	0.09
IT	-0.61	-0.12	0.03	0.12	0.00	0.01	0.94	0.15	0.16	0.13	0.15	0.01	-0.01	-0.05	0.08	0.10	-0.01	-0.28	0.10
JP	-0.22	-0.16	0.06	0.20	0.02	0.07	0.69	0.24	0.01	0.00	0.37	0.04	0.01	0.02	0.06	0.11	-0.01	-0.05	0.09
NL	-0.65	-0.17	0.04	0.10	0.00	0.03	1.00	0.15	0.19	0.10	0.34	0.02	-0.02	-0.05	0.05	0.05	-0.01	-0.12	0.07
UK	-0.30	-0.19	0.05	0.17	0.01	0.03	0.80	0.21	0.07	0.03	0.40	0.03	-0.01	-0.02	0.04	0.05	-0.01	-0.07	0.07
US	-0.16	-0.22	0.06	0.27	0.00	0.00	0.64	0.30	-0.14	-0.05	0.37	0.04	0.01	0.02	0.04	0.10	-0.01	-0.06	0.09

CHAPTER 5. FACTORS DEMAND IN ICT-RELATED INDUSTRIES

Table 5.11: Short Term Morishima Elasticities of Substitution ( $\mu_{ij}$ )

<i>Electrical &amp; Optical Equipment</i>												
	$\mu_{HLSL}$	$\mu_{LSHS}$	$\mu_{HST}$	$\mu_{THS}$	$\mu_{LST}$	$\mu_{TLS}$	$\mu_{HSM}$	$\mu_{MHS}$	$\mu_{LSM}$	$\mu_{MLS}$	$\mu_{TM}$	$\mu_{MT}$
AT	0.88	-0.23	-0.60	-0.20	-0.62	0.69	-0.18	-0.32	0.95	0.54	-0.40	-0.65
AU	0.79	0.16	0.06	0.17	0.05	0.66	0.26	0.08	0.90	0.51	0.28	0.02
BE	0.75	0.33	0.59	0.32	0.58	0.65	0.46	0.24	0.90	0.49	0.83	0.55
DE	0.75	0.46	-2.29	0.54	-2.30	0.65	0.61	0.37	0.92	0.52	-2.11	-2.33
ES	0.57	0.45	0.34	0.44	0.33	0.48	0.56	0.36	0.69	0.35	0.55	0.31
FI	0.37	0.53	0.22	0.51	0.21	0.29	0.62	0.43	0.48	0.17	0.41	0.19
FR	0.70	0.16	0.41	0.15	0.39	0.57	0.24	0.07	0.79	0.43	0.61	0.37
IT	0.92	-1.04	0.08	-1.03	0.05	0.63	-1.13	-1.12	0.86	0.49	0.27	0.03
JP	0.57	0.55	0.25	0.54	0.25	0.50	0.68	0.46	0.71	0.36	0.46	0.22
NL	0.80	-0.72	0.07	-0.71	0.05	0.56	-0.79	-0.80	0.76	0.43	0.25	0.02
UK	0.74	0.10	0.29	0.10	0.28	0.60	0.17	0.02	0.82	0.46	0.50	0.25
US	0.47	0.78	0.39	0.77	0.39	0.43	0.96	0.68	0.65	0.28	0.62	0.36

<i>Transport &amp; Storage &amp; Communication</i>												
	$\mu_{HLSL}$	$\mu_{LSHS}$	$\mu_{HST}$	$\mu_{THS}$	$\mu_{LST}$	$\mu_{TLS}$	$\mu_{HSM}$	$\mu_{MHS}$	$\mu_{LSM}$	$\mu_{MLS}$	$\mu_{TM}$	$\mu_{MT}$
AT	0.11	-0.54	0.79	-0.53	0.90	0.84	0.55	-0.56	1.10	0.19	1.15	0.78
AU	0.06	-0.14	0.65	-0.14	0.77	0.92	0.67	-0.14	0.76	0.12	0.60	0.64
BE	0.02	-0.24	0.67	-0.23	0.80	0.86	0.61	-0.24	0.73	0.10	0.67	0.67
DE	0.02	-0.62	0.61	-0.62	0.74	1.06	0.40	-0.63	0.92	0.20	0.60	0.62
ES	0.23	0.43	0.82	0.45	0.91	0.67	1.08	0.43	0.78	0.07	1.01	0.78
FI	0.38	0.66	0.74	0.67	0.82	0.89	1.27	0.65	0.91	0.11	0.84	0.69
FR	0.40	0.39	0.51	0.37	0.59	1.34	1.11	0.37	1.03	0.21	0.30	0.47
IT	-0.13	-1.07	0.66	-1.07	0.81	0.94	0.11	-1.08	0.91	0.19	0.77	0.69
JP	0.41	0.41	0.78	0.41	0.85	0.92	1.16	0.39	1.09	0.18	1.02	0.73
NL	-0.06	-0.83	0.68	-0.83	0.82	0.92	0.27	-0.84	0.90	0.18	0.80	0.69
UK	0.36	0.28	0.68	0.28	0.77	1.05	1.04	0.27	1.03	0.20	0.75	0.64
US	0.33	0.68	0.85	0.69	0.93	0.65	1.30	0.67	0.86	0.04	1.13	0.79

<i>Wholesale &amp; Retail Trade</i>												
	$\mu_{HLSL}$	$\mu_{LSHS}$	$\mu_{HST}$	$\mu_{THS}$	$\mu_{LST}$	$\mu_{TLS}$	$\mu_{HSM}$	$\mu_{MHS}$	$\mu_{LSM}$	$\mu_{MLS}$	$\mu_{TM}$	$\mu_{MT}$
AT	0.29	-0.09	0.91	0.23	0.67	-0.11	0.42	-0.12	1.03	0.46	1.49	0.72
AU	0.24	-0.08	0.97	0.18	0.73	0.01	0.39	-0.10	0.96	0.43	1.41	0.78
BE	0.29	0.29	0.91	0.54	0.73	-0.04	0.68	0.29	0.86	0.36	1.38	0.80
DE	0.35	-0.03	0.88	0.31	0.66	-0.12	0.51	-0.07	1.11	0.47	1.55	0.70
ES	0.46	0.43	0.70	0.87	0.56	-0.45	0.83	0.41	1.00	0.44	1.57	0.61
FI	0.51	0.73	0.81	1.01	0.72	-0.05	1.10	0.71	0.97	0.36	1.46	0.78
FR	0.42	0.28	0.70	0.75	0.53	-0.51	0.71	0.26	1.01	0.45	1.59	0.58
IT	-0.16	-1.21	0.83	-0.60	0.39	-0.93	-0.52	-1.22	0.97	0.46	1.67	0.44
JP	0.54	0.77	0.74	1.11	0.65	-0.21	1.15	0.74	1.00	0.36	1.53	0.71
NL	-0.19	-1.40	1.14	-1.07	0.67	-0.12	-0.64	-1.43	1.05	0.48	1.50	0.71
UK	0.35	0.15	0.96	0.38	0.77	0.14	0.60	0.13	0.99	0.44	1.40	0.82
US	0.56	0.76	0.82	1.01	0.74	0.04	1.16	0.72	1.04	0.37	1.49	0.79

<i>Fin., Ins., Real Estate &amp; Business</i>												
	$\mu_{HLSL}$	$\mu_{LSHS}$	$\mu_{HST}$	$\mu_{THS}$	$\mu_{LST}$	$\mu_{TLS}$	$\mu_{HSM}$	$\mu_{MHS}$	$\mu_{LSM}$	$\mu_{MLS}$	$\mu_{TM}$	$\mu_{MT}$
AT	-0.46	0.25	0.47	0.52	0.43	0.10	1.50	0.56	0.83	0.18	0.90	0.44
AU	-0.39	0.32	0.47	0.66	0.43	-0.08	1.39	0.70	0.73	0.02	0.89	0.45
BE	-0.60	0.20	0.57	0.55	0.52	-0.05	1.46	0.59	0.71	0.01	0.93	0.54
DE	-0.80	0.05	0.69	0.33	0.64	0.16	1.61	0.38	0.80	0.14	1.00	0.66
ES	-0.36	0.36	0.63	0.74	0.58	-0.10	1.34	0.79	0.68	-0.10	0.98	0.61
FI	-0.64	0.26	0.64	0.78	0.57	-0.44	1.31	0.83	0.48	-0.44	0.98	0.62
FR	-0.34	0.35	0.49	0.68	0.45	-0.05	1.38	0.72	0.74	0.03	0.91	0.47
IT	-0.37	0.28	0.40	0.51	0.36	0.15	1.52	0.56	0.90	0.25	0.88	0.37
JP	-0.30	0.39	0.71	0.76	0.66	-0.03	1.34	0.81	0.70	-0.09	1.03	0.69
NL	-0.54	0.21	0.50	0.50	0.46	0.06	1.50	0.54	0.80	0.14	0.91	0.47
UK	-0.41	0.33	0.64	0.71	0.58	-0.10	1.36	0.75	0.67	-0.09	0.98	0.61
US	-0.52	0.32	0.69	0.82	0.63	-0.37	1.30	0.87	0.52	-0.42	1.02	0.67

Table 5.12: Long Term Morishima Elasticities of Substitution ( $\mu_{ij}^*$ )

		<i>Electrical &amp; Optical Equipment</i>																		
	$\mu^*_{HSLs}$	$\mu^*_{LSHS}$	$\mu^*_{HST}$	$\mu^*_{THS}$	$\mu^*_{LST}$	$\mu^*_{TLS}$	$\mu^*_{HSM}$	$\mu^*_{MHS}$	$\mu^*_{LSM}$	$\mu^*_{NLS}$	$\mu^*_{TLM}$	$\mu^*_{MT}$	$\mu^*_{KHS}$	$\mu^*_{HSK}$	$\mu^*_{KLS}$	$\mu^*_{LSK}$	$\mu^*_{KT}$	$\mu^*_{TK}$	$\mu^*_{KM}$	$\mu^*_{MK}$
AT	0.86	-0.32	-0.76	-0.24	-0.79	0.67	-0.67	-0.39	0.49	0.55	-0.99	-0.81	-0.38	0.03	0.03	0.08	-0.80	0.03	0.31	0.12
AU	0.76	0.14	0.03	0.18	0.01	0.65	-0.17	0.07	0.45	0.52	-0.20	-0.01	0.07	0.05	0.05	0.07	-0.01	0.05	0.29	0.10
BE	0.74	0.31	0.59	0.32	0.57	0.65	0.00	0.23	0.43	0.51	0.34	0.55	0.22	0.05	0.06	0.06	0.53	0.07	0.30	0.09
DE	0.74	0.45	-2.89	0.62	-2.91	0.57	0.14	0.37	0.45	0.54	-3.13	-2.93	0.35	0.02	0.07	0.03	-2.92	-0.02	0.27	0.04
ES	0.55	0.43	0.32	0.44	0.31	0.47	0.16	0.35	0.30	0.35	0.12	0.28	0.32	0.07	0.08	0.07	0.28	0.08	0.26	0.12
FI	0.33	0.51	0.19	0.52	0.17	0.25	0.25	0.42	0.12	0.15	0.01	0.15	0.39	0.10	0.04	0.07	0.15	0.09	0.25	0.15
FR	0.67	0.13	0.41	0.14	0.38	0.56	-1.18	0.05	0.38	0.44	0.18	0.36	0.05	0.04	0.05	0.06	0.35	0.06	0.25	0.09
IT	0.88	-1.25	0.07	-1.22	0.02	0.62	-1.68	-1.32	0.44	0.51	-0.18	-0.01	-1.30	-0.01	0.02	0.06	-0.01	0.05	0.25	0.09
JP	0.55	0.53	0.22	0.55	0.21	0.47	0.27	0.45	0.31	0.36	0.03	0.18	0.42	0.11	0.10	0.09	0.18	0.10	0.29	0.16
NL	0.75	-0.81	0.08	-0.79	0.03	0.55	-1.22	-0.89	0.37	0.45	-0.16	0.01	-0.87	0.00	0.03	0.03	0.01	0.02	0.20	0.04
UK	0.71	0.04	0.27	0.06	0.25	0.59	-0.27	-0.04	0.41	0.47	0.06	0.22	-0.04	0.06	0.05	0.08	0.22	0.08	0.28	0.12
US	0.45	0.78	0.36	0.78	0.36	0.41	0.51	0.68	0.22	0.28	0.15	0.33	0.59	0.10	0.18	0.07	0.32	0.08	0.30	0.13

		<i>Transport &amp; Storage &amp; Communication</i>																		
	$\mu^*_{HSLs}$	$\mu^*_{LSHS}$	$\mu^*_{HST}$	$\mu^*_{THS}$	$\mu^*_{LST}$	$\mu^*_{TLS}$	$\mu^*_{HSM}$	$\mu^*_{MHS}$	$\mu^*_{LSM}$	$\mu^*_{NLS}$	$\mu^*_{TLM}$	$\mu^*_{MT}$	$\mu^*_{KHS}$	$\mu^*_{HSK}$	$\mu^*_{KLS}$	$\mu^*_{LSK}$	$\mu^*_{KT}$	$\mu^*_{TK}$	$\mu^*_{KM}$	$\mu^*_{MK}$
AT	0.08	-0.56	0.81	-0.55	0.91	0.83	-0.48	-0.58	0.05	0.18	0.11	0.79	-0.56	0.15	0.01	0.16	0.79	0.18	0.13	0.17
AU	0.02	-0.18	0.68	-0.16	0.80	0.87	-0.08	-0.17	0.00	0.10	-0.13	0.67	-0.17	0.23	0.01	0.23	0.70	0.27	0.17	0.25
BE	-0.03	-0.27	0.70	-0.25	0.82	0.82	-0.14	-0.26	-0.02	0.09	-0.07	0.69	-0.25	0.19	0.01	0.19	0.71	0.22	0.15	0.21
DE	-0.02	-0.65	0.65	-0.65	0.77	1.02	-0.43	-0.66	0.08	0.19	-0.21	0.64	-0.64	0.15	0.01	0.16	0.68	0.18	0.14	0.17
ES	0.21	0.42	0.83	0.44	0.93	0.64	0.25	0.42	-0.06	0.06	0.18	0.79	0.41	0.22	0.03	0.21	0.79	0.24	0.17	0.23
FI	0.36	0.66	0.76	0.67	0.84	0.84	0.35	0.65	-0.02	0.10	-0.07	0.71	0.62	0.31	0.06	0.30	0.74	0.35	0.22	0.33
FR	0.38	0.38	0.56	0.37	0.64	1.27	0.16	0.37	0.08	0.20	-0.59	0.52	0.36	0.21	0.03	0.21	0.57	0.26	0.17	0.23
IT	-0.17	-1.09	0.70	-1.08	0.82	0.92	-0.71	-1.09	0.07	0.18	-0.05	0.70	-1.08	0.11	0.01	0.12	0.73	0.14	0.11	0.13
JP	0.39	0.40	0.80	0.41	0.87	0.89	0.12	0.39	0.04	0.17	-0.02	0.74	0.38	0.22	0.03	0.21	0.77	0.24	0.15	0.23
NL	-0.10	-0.86	0.71	-0.85	0.83	0.89	-0.56	-0.87	0.06	0.18	-0.04	0.71	-0.85	0.18	0.01	0.19	0.74	0.22	0.16	0.21
UK	0.34	0.29	0.71	0.29	0.79	1.03	0.09	0.27	0.07	0.20	-0.20	0.66	0.27	0.10	0.02	0.10	0.70	0.11	0.10	0.11
US	0.31	0.67	0.86	0.70	0.94	0.63	0.35	0.67	-0.10	0.04	0.17	0.80	0.62	0.18	0.04	0.17	0.80	0.19	0.15	0.19

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<i>Wholesale &amp; Retail Trade</i>																				
	$\mu^{*HSLS}$	$\mu^{*SHS}$	$\mu^{*HST}$	$\mu^{*THS}$	$\mu^{*LST}$	$\mu^{*TLS}$	$\mu^{*HSM}$	$\mu^{*MHS}$	$\mu^{*LSM}$	$\mu^{*MLS}$	$\mu^{*TM}$	$\mu^{*MT}$	$\mu^{*KHS}$	$\mu^{*HSK}$	$\mu^{*KLS}$	$\mu^{*LSK}$	$\mu^{*KT}$	$\mu^{*TK}$	$\mu^{*KOM}$	$\mu^{*MK}$
AT	0.24	0.21	0.81	0.53	0.66	-0.05	-0.27	0.17	0.37	0.53	1.00	0.71	0.21	-0.75	-0.02	-1.21	0.64	-1.45	-0.58	-1.39
AU	0.30	0.11	0.91	0.37	0.72	0.00	-0.06	0.09	0.44	0.45	0.95	0.78	0.13	-0.12	0.02	-0.24	0.73	-0.30	-0.03	-0.29
BE	0.32	0.38	0.88	0.63	0.73	-0.02	0.18	0.38	0.37	0.38	0.96	0.80	0.38	-0.27	0.03	-0.38	0.74	-0.46	-0.19	-0.45
DE	0.39	0.11	0.83	0.44	0.65	-0.14	-0.11	0.06	0.44	0.47	0.94	0.70	0.12	-0.07	0.01	-0.16	0.65	-0.20	0.11	-0.19
ES	0.44	0.52	0.61	1.01	0.50	-0.52	0.15	0.50	0.37	0.49	1.19	0.55	0.47	-0.74	-0.01	-0.93	0.50	-1.21	-0.44	-1.07
FI	0.52	0.74	0.80	1.01	0.72	-0.04	0.49	0.72	0.37	0.37	0.91	0.78	0.63	-0.21	0.09	-0.22	0.73	-0.27	0.04	-0.27
FR	0.42	0.39	0.65	0.85	0.52	-0.52	0.12	0.36	0.42	0.48	1.14	0.57	0.38	-0.29	0.01	-0.43	0.53	-0.56	-0.11	-0.50
IT	0.05	-0.50	0.64	0.13	0.35	-1.04	-0.64	-0.52	0.45	0.47	1.33	0.40	-0.46	-0.02	0.01	-0.28	0.37	-0.40	-0.06	-0.32
JP	0.55	0.79	0.71	1.17	0.63	-0.18	0.40	0.79	0.27	0.42	0.97	0.69	0.49	-1.12	-0.05	-1.16	0.62	-1.43	-0.49	-1.36
NL	0.02	-0.70	0.98	-0.38	0.66	-0.12	-0.81	-0.74	0.46	0.49	0.98	0.71	-0.67	0.02	0.01	-0.21	0.67	-0.26	0.04	-0.25
UK	0.38	0.26	0.93	0.47	0.77	0.14	0.07	0.23	0.44	0.45	0.89	0.82	0.27	-0.12	0.02	-0.20	0.77	-0.24	0.03	-0.24
US	0.57	0.77	0.81	1.02	0.74	0.06	0.45	0.74	0.34	0.39	0.84	0.80	0.61	-0.32	0.07	-0.34	0.74	-0.41	0.00	-0.41

<i>Fin., Ins., Real Estate &amp; Business</i>																				
	$\mu^{*HSLS}$	$\mu^{*LSHS}$	$\mu^{*HST}$	$\mu^{*THS}$	$\mu^{*LST}$	$\mu^{*TLS}$	$\mu^{*HSM}$	$\mu^{*MHS}$	$\mu^{*LSM}$	$\mu^{*MLS}$	$\mu^{*TM}$	$\mu^{*MT}$	$\mu^{*KHS}$	$\mu^{*HSK}$	$\mu^{*KLS}$	$\mu^{*LSK}$	$\mu^{*KT}$	$\mu^{*TK}$	$\mu^{*KOM}$	$\mu^{*MK}$
AT	-0.52	0.18	0.28	0.44	0.24	0.13	1.32	0.48	0.52	0.22	0.63	0.26	0.32	0.08	0.04	0.21	0.23	-0.04	0.43	0.20
AU	-0.37	0.31	0.31	0.64	0.28	-0.05	1.16	0.67	0.43	0.06	0.64	0.30	0.48	0.09	0.03	0.17	0.27	-0.03	0.39	0.16
BE	-0.62	0.17	0.47	0.49	0.43	0.00	1.28	0.53	0.43	0.05	0.70	0.45	0.37	0.07	0.01	0.17	0.41	0.01	0.37	0.16
DE	-1.03	-0.13	0.61	0.13	0.56	0.23	1.58	0.18	0.50	0.19	0.75	0.58	0.05	0.05	0.03	0.27	0.54	0.09	0.45	0.25
ES	-0.31	0.36	0.55	0.73	0.51	-0.04	1.08	0.77	0.37	-0.04	0.71	0.53	0.54	0.12	-0.01	0.20	0.49	0.04	0.42	0.18
FI	-0.54	0.28	0.57	0.78	0.51	-0.34	1.05	0.81	0.20	-0.33	0.73	0.55	0.56	0.13	-0.29	0.21	0.51	0.04	0.40	0.18
FR	-0.32	0.34	0.34	0.66	0.30	-0.01	1.14	0.69	0.44	0.07	0.65	0.32	0.49	0.11	0.04	0.20	0.29	-0.02	0.41	0.18
IT	-0.46	0.19	0.02	0.42	-0.01	0.15	1.33	0.46	0.55	0.28	0.54	0.00	0.30	0.11	0.04	0.26	-0.02	-0.13	0.48	0.26
JP	-0.24	0.39	0.65	0.75	0.61	0.05	1.06	0.79	0.38	-0.02	0.74	0.63	0.55	0.17	0.02	0.26	0.59	0.10	0.46	0.24
NL	-0.58	0.17	0.38	0.44	0.35	0.09	1.31	0.49	0.49	0.17	0.64	0.36	0.32	0.05	0.03	0.14	0.33	-0.02	0.38	0.13
UK	-0.38	0.33	0.58	0.69	0.54	-0.04	1.10	0.74	0.37	-0.05	0.71	0.56	0.52	0.08	-0.02	0.14	0.52	0.02	0.38	0.12
US	-0.42	0.34	0.64	0.82	0.58	-0.26	1.00	0.86	0.21	-0.31	0.73	0.62	0.57	0.15	-0.29	0.23	0.57	0.07	0.44	0.20



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Figure 5.5: Externalities

(a) Short Term Externalities ( $\Xi_{UVC}$  and  $\Xi_{S_i}$ )

Electrical & Optical Equipment					
	$\Xi_{UCV}$	$\Xi_{HS}$	$\Xi_{LS}$	$\Xi_T$	$\Xi_M$
AT	-0.05	0.01	-0.08	1.40	-0.07
AU	-0.05	-0.01	-0.08	0.79	-0.07
BE	-0.05	-0.02	-0.08	0.32	-0.07
DE	-0.05	-0.02	-0.08	3.15	-0.07
ES	-0.05	-0.02	-0.10	0.54	-0.06
FI	-0.05	-0.02	-0.12	0.64	-0.06
FR	-0.05	-0.01	-0.09	0.48	-0.06
IT	-0.05	0.06	-0.09	0.79	-0.06
JP	-0.05	-0.03	-0.10	0.61	-0.06
NL	-0.05	0.04	-0.09	0.79	-0.06
UK	-0.05	0.00	-0.09	0.59	-0.06
US	-0.05	-0.04	-0.10	0.50	-0.07

Transport & Storage & Communication					
	$\Xi_{UCV}$	$\Xi_{HS}$	$\Xi_{LS}$	$\Xi_T$	$\Xi_M$
AT	0.12	-0.03	0.10	0.07	0.16
AU	0.12	0.01	0.09	0.01	0.15
BE	0.12	0.00	0.09	0.02	0.15
DE	0.12	-0.04	0.10	0.00	0.15
ES	0.12	0.07	0.09	0.06	0.15
FI	0.12	0.09	0.09	0.03	0.15
FR	0.12	0.06	0.10	-0.05	0.15
IT	0.12	-0.08	0.10	0.03	0.15
JP	0.12	0.06	0.10	0.05	0.16
NL	0.12	-0.06	0.10	0.03	0.15
UK	0.12	0.05	0.10	0.01	0.16
US	0.12	0.09	0.09	0.07	0.15

Wholesale & Retail Trade					
	$\Xi_{UCV}$	$\Xi_{HS}$	$\Xi_{LS}$	$\Xi_T$	$\Xi_M$
AT	0.01	0.38	-0.06	0.33	0.03
AU	0.01	0.37	-0.07	0.27	0.03
BE	0.01	0.24	-0.09	0.24	0.03
DE	0.01	0.36	-0.05	0.36	0.03
ES	0.01	0.19	-0.06	0.47	0.03
FI	0.01	0.09	-0.08	0.27	0.03
FR	0.01	0.25	-0.06	0.47	0.03
IT	0.01	0.76	-0.07	0.64	0.03
JP	0.01	0.07	-0.08	0.34	0.03
NL	0.01	0.86	-0.06	0.34	0.03
UK	0.01	0.29	-0.07	0.22	0.03
US	0.01	0.08	-0.07	0.25	0.03

Fin., Ins., Real Estate & Business					
	$\Xi_{UCV}$	$\Xi_{HS}$	$\Xi_{LS}$	$\Xi_T$	$\Xi_M$
AT	-0.04	-0.20	-0.01	0.23	-0.05
AU	-0.04	-0.15	0.00	0.23	-0.05
BE	-0.04	-0.18	0.00	0.18	-0.05
DE	-0.04	-0.25	-0.01	0.12	-0.05
ES	-0.04	-0.12	0.01	0.15	-0.05
FI	-0.04	-0.11	0.03	0.14	-0.05
FR	-0.04	-0.14	0.00	0.21	-0.05
IT	-0.04	-0.20	-0.01	0.27	-0.05
JP	-0.04	-0.12	0.01	0.11	-0.05
NL	-0.04	-0.20	-0.01	0.21	-0.05
UK	-0.04	-0.13	0.01	0.14	-0.05
US	-0.04	-0.10	0.02	0.11	-0.05

(b) Long Term Externalities ( $\Xi_{UVC}^*$  and  $\Xi_{S_i}^*$ )

Electrical & Optical Equipment						
	$\Xi_{UCV}^*$	$\Xi_{HS}^*$	$\Xi_{LS}^*$	$\Xi_T^*$	$\Xi_M^*$	$\Xi_K^*$
AT	-0.05	0.06	-0.07	1.59	-0.07	0.05
AU	-0.05	0.02	-0.07	0.85	-0.07	0.05
BE	-0.05	0.01	-0.07	0.34	-0.07	0.05
DE	-0.05	0.00	-0.07	3.52	-0.07	0.06
ES	-0.05	0.00	-0.08	0.58	-0.07	0.05
FI	-0.05	-0.01	-0.09	0.70	-0.07	0.05
FR	-0.05	0.02	-0.08	0.51	-0.07	0.05
IT	-0.05	0.14	-0.07	0.85	-0.07	0.05
JP	-0.05	-0.01	-0.08	0.67	-0.07	0.05
NL	-0.05	0.11	-0.07	0.83	-0.07	0.06
UK	-0.05	0.03	-0.07	0.63	-0.07	0.05
US	-0.05	-0.03	-0.08	0.54	-0.07	0.05

Transport & Storage & Communication						
	$\Xi_{UCV}^*$	$\Xi_{HS}^*$	$\Xi_{LS}^*$	$\Xi_T^*$	$\Xi_M^*$	$\Xi_K^*$
AT	0.11	-0.04	0.09	0.06	0.15	-0.05
AU	0.11	-0.01	0.08	0.01	0.14	-0.04
BE	0.11	-0.01	0.08	0.02	0.14	-0.04
DE	0.11	-0.05	0.09	0.01	0.15	-0.05
ES	0.11	0.06	0.08	0.06	0.14	-0.04
FI	0.11	0.08	0.08	0.02	0.14	-0.03
FR	0.11	0.05	0.09	-0.04	0.15	-0.04
IT	0.12	-0.10	0.09	0.03	0.15	-0.05
JP	0.11	0.05	0.09	0.04	0.15	-0.04
NL	0.11	-0.07	0.09	0.03	0.14	-0.04
UK	0.12	0.05	0.09	0.02	0.15	-0.06
US	0.11	0.08	0.08	0.07	0.15	-0.04

Wholesale & Retail Trade						
	$\Xi_{UCV}^*$	$\Xi_{HS}^*$	$\Xi_{LS}^*$	$\Xi_T^*$	$\Xi_M^*$	$\Xi_K^*$
AT	0.14	-0.19	0.00	0.69	0.29	-1.03
AU	-0.03	-0.17	-0.16	0.35	0.06	-0.68
BE	-0.01	-0.13	-0.18	0.34	0.08	-0.73
DE	-0.04	-0.15	-0.14	0.46	0.08	-0.64
ES	0.09	-0.08	-0.06	0.90	0.22	-0.93
FI	-0.03	-0.07	-0.18	0.34	0.08	-0.67
FR	0.00	-0.13	-0.13	0.73	0.11	-0.75
IT	-0.02	-0.27	-0.15	0.97	0.07	-0.69
JP	0.13	0.05	-0.04	0.71	0.30	-1.02
NL	-0.03	-0.28	-0.14	0.45	0.07	-0.66
UK	-0.03	-0.14	-0.16	0.27	0.06	-0.66
US	-0.01	-0.05	-0.15	0.34	0.12	-0.72

Fin., Ins., Real Estate & Business						
	$\Xi_{UCV}^*$	$\Xi_{HS}^*$	$\Xi_{LS}^*$	$\Xi_T^*$	$\Xi_M^*$	$\Xi_K^*$
AT	0.04	0.15	0.01	1.04	-0.01	0.37
AU	0.03	0.11	-0.01	1.00	-0.01	0.37
BE	0.03	0.14	-0.01	0.78	-0.01	0.37
DE	0.05	0.21	0.02	0.59	0.01	0.36
ES	0.04	0.10	-0.01	0.66	-0.01	0.37
FI	0.04	0.09	-0.03	0.63	-0.01	0.37
FR	0.04	0.11	0.00	0.95	-0.01	0.37
IT	0.05	0.16	0.03	1.38	0.00	0.36
JP	0.05	0.10	0.00	0.52	0.00	0.36
NL	0.03	0.15	-0.01	0.91	-0.02	0.38
UK	0.03	0.10	-0.02	0.62	-0.02	0.38
US	0.04	0.08	-0.02	0.54	-0.01	0.37

$$\frac{\partial \ln P_K}{\partial \ln K} = \frac{S_K^* (S_K^* - 1) + \alpha_{KK}}{S_K^*} \quad (5.25)$$

Knowing that:  $\sigma_{KK}^* = \frac{1}{|S_K^*|} \sum_{i=HS,LS,T,M,K} |S_i^*| \times \frac{\partial \ln K}{\partial \ln P_i}$

We can deduce:

$$\sigma_{KK}^* = -\frac{1 + |S_K^*|}{S_K^* (S_K^* - 1) + \alpha_{KK}} \quad (5.26)$$

**The cross price elasticities between variable factors and non-ICT capital**

$$\begin{aligned} \frac{\partial P_K}{\partial P_i} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial P_i} \\ \frac{\partial P_K}{\partial P_i} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial P_i} \\ &= -\frac{Y \partial \frac{Cvu}{K} \frac{d \ln Cvu}{d \ln K/Y}}{P_i \partial \ln P_i} \\ &= -\frac{Y}{P_i} \left( \frac{1}{K} \frac{d \ln Cvu}{d \ln K/Y} \frac{\partial Cvu}{\partial \ln P_i} + \frac{Cvu}{K} \alpha_{iK} \right) \\ &= -\frac{Y}{P_i} \frac{Cvu}{K} (S_K^* S_i^* + \alpha_{iK}) \\ &= \frac{P_K}{P_i} \left( \frac{S_K^* S_i^* + \alpha_{iK}}{S_K^*} \right) \end{aligned}$$

Then

$$\frac{\partial \ln P_K}{\partial \ln P_i} = \frac{S_K^* S_i^* + \alpha_{iK}}{S_K^*} \quad (5.27)$$

From the total differential, considering  $Y$ ,  $\tilde{k}_T$ , and  $P_j \forall j \neq i$  fixed,  $dP_K = \frac{\partial P_K}{\partial P_i} dP_i + \frac{\partial P_K}{\partial K} \frac{dK}{dP_i} dP_i = 0$

We deduce

$$\begin{aligned} \frac{dK}{dP_i} &= -\frac{\partial P_K / \partial P_i}{\partial P_K / \partial K} \\ &= -\frac{P_K}{P_i} \left( \frac{S_K^* S_i^* + \alpha_{iK}}{S_K^*} \right) / \frac{P_K}{K} \left( \frac{S_K^* (S_K^* - 1) + \alpha_{KK}}{S_K^*} \right) \\ &= -\frac{K}{P_i} \frac{S_K^* S_i^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \end{aligned}$$

So

$$\frac{d \ln K}{d \ln P_i} = -\frac{S_K^* S_i^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \quad (5.28)$$

As  $\sigma_{iK}^* = \frac{1}{|S_i^*|} \sum_{j=HS,LS,T,M,K} |S_j^*| \times \frac{\partial \ln K}{\partial \ln P_j}$

$$\sigma_{iK}^* = -\frac{1 + |S_K^*|}{S_i^*} \times \frac{S_i^* S_K^* + \alpha_{iK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \quad (5.29)$$

**The own and cross price elasticities between variable factors**

With  $P_h$ ,  $h \neq j$ ,  $P_K$ ,  $Y$ ,  $\tilde{k}_T$  fixed, we have for all  $i$ :

$$\begin{aligned} \frac{dX_i}{dP_j} &= \frac{\partial X_i}{\partial P_j} + \frac{\partial X_i}{\partial K} \frac{dK}{dP_j} \\ &= \frac{X_i}{P_i} \left( \frac{S_i^* S_j^* + \alpha_{ij}}{S_i^*} \right) - \frac{X_i}{K} \left( \frac{S_i^* S_K^* + \alpha_{iK}}{S_i^*} \right) \frac{K}{P_j} \left( \frac{S_j^* S_K^* + \alpha_{jK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right) \\ &= \frac{X_i}{P_i} \left( \frac{S_i^* S_j^* + \alpha_{ij}}{S_i^*} - \frac{S_i^* S_K^* + \alpha_{iK}}{S_i^*} \times \frac{S_j^* S_K^* + \alpha_{jK}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right) \\ S_K^* &= -\frac{P_K K^*}{Y C v u} \\ &= \alpha_K + \alpha_{KK} \ln \left( \frac{K}{Y} \right)^* + \alpha_{HSK} \ln \left( \frac{P_{HS}}{P_M} \right) + \alpha_{LSK} \ln \left( \frac{P_{LS}}{P_M} \right) \\ &\quad + \alpha_{TK} \ln \left( \frac{P_T}{P_M} \right) + \alpha_{KET} \ln (\tilde{k}_T) + \alpha_{KY} \ln (Y) + \alpha_{Kt} \times t \end{aligned} \quad (5.30)$$

•  $i \neq j$  leads to:

$$\frac{d \ln X_i}{d \ln P_j} = \frac{S_i^* S_j^* + \alpha_{ij}}{S_i^*} - \frac{(S_i^* S_K^* + \alpha_{iK})(S_j^* S_K^* + \alpha_{jK})}{S_i^* [S_K^* (S_K^* - 1) + \alpha_{KK}]} \quad (5.31)$$

Therefore:

$$\sigma_{ij}^* = \frac{1 + |S_K^*|}{S_i^* S_j^*} \left[ S_i^* S_j^* + \alpha_{ij} - \frac{(S_i^* S_K^* + \alpha_{iK})(S_j^* S_K^* + \alpha_{jK})}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \quad (5.32)$$

•  $i = j$  leads to:

$$\frac{d \ln X_i}{d \ln P_i} = \frac{S_i^* (S_i^* - 1) + \alpha_{ii}}{S_i^*} - \frac{(S_i^* S_K^* + \alpha_{iK})^2}{S_i^* [S_K^* (S_K^* - 1) + \alpha_{KK}]} \quad (5.33)$$

Therefore:

$$\sigma_{ii}^* = \frac{1 + |S_K^*|}{S_i^{*2}} \left[ \alpha_{ii} + S_i^* (S_i^* - 1) - \frac{(S_i^* S_K^* + \alpha_{iK})^2}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \quad (5.34)$$

### 5.8.3 Calculation of the long run return to scale, technical progress and externalities

**The long run return to scale**

Considering  $P_i \forall i \in \{HS, LS, M, T, K\}$ ,  $t$  and  $\tilde{k}_T$  fixed

$$\frac{d \ln C v u_{LT}}{d \ln Y} = \frac{\partial \ln C v u}{\partial \ln Y} + Y \left[ \frac{\partial \ln C v u}{\partial \ln \frac{K}{Y}} \frac{d \ln \frac{K}{Y}}{d Y} \right]$$

$$\begin{aligned}
 \frac{\partial P_K}{\partial Y} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial Y} \\
 &= -\frac{\partial Cvu}{\partial K} - Y \frac{\partial}{\partial Y} \left( \frac{\partial Cvu}{\partial K} \right) \\
 &= -\frac{Cvu}{K} \frac{\partial \ln Cvu}{\partial \ln K} - Y \frac{\partial}{\partial Y} \left( \frac{Cvu}{K} \frac{\partial \ln Cvu}{\partial \ln K} \right) \\
 &= -\frac{Cvu}{K} S_K^* - \frac{Y}{K} \left[ \frac{\partial Cvu}{\partial Y} S_K^* + Cvu \frac{\partial S_K^*}{\partial Y} \right] \\
 &= -\frac{Cvu}{K} S_K^* - \frac{Y}{K} \left[ \frac{Cvu}{Y} \xi_Y^* S_K^* + \frac{Cvu}{Y} \alpha_{KY} \right] \\
 &= -\frac{Y \times Cvu \times P_K}{Y \times K \times P_K} [S_K^* + S_K^* \xi_Y^* + \alpha_{KY}] \\
 &= \frac{P_K}{Y S_K^*} [S_K^* (1 + \xi_Y^*) + \alpha_{KY}]
 \end{aligned}$$

We write the total differential considering  $\tilde{k}_T$  and  $P_i \forall i$  fixed,  $dP_K = \frac{\partial P_K}{\partial Y} dY + \frac{\partial P_K}{\partial K} \frac{dK}{dY} dY = 0$

which leads to:

$$\frac{dK}{dY} = -\frac{\partial P_K / \partial Y}{\partial P_K / \partial K}$$

$$\begin{aligned}
 \text{Then} \\
 \frac{d \ln \frac{K}{Y}}{dY} &= \frac{Y}{K} \frac{d \frac{K}{Y}}{dY} \\
 &= \frac{Y}{K} \left[ \frac{Y \frac{dK}{dY} - K}{Y^2} \right] \\
 &= \frac{1}{K} \frac{dK}{dY} - \frac{1}{Y} \\
 &= \frac{1}{K} \frac{P_K}{Y S_K^*} [S_K^* (1 + \xi_Y^*) + \alpha_{KY}] - \frac{1}{Y} \\
 &= \frac{1}{K} \frac{P_K}{K S_K^*} [S_K^* (S_K^* - 1) + \alpha_{KK}] - \frac{1}{Y} \\
 &= \frac{1}{Y} \frac{[S_K^* (1 + \xi_Y^*) + \alpha_{KY}]}{[S_K^* (S_K^* - 1) + \alpha_{KK}]} - \frac{1}{Y}
 \end{aligned}$$

Therefore

$$\eta_Y^* = -\left( \frac{\partial \ln Cvu_{LT}}{\partial \ln Y} \right)_{LT} = -\left( \xi_Y^* + S_K^* \left\{ \frac{[S_K^* (1 + \xi_Y^*) + \alpha_{KY}]}{[S_K^* (S_K^* - 1) + \alpha_{KK}]} - 1 \right\} \right) \quad (5.35)$$

### The long run technical progress

The calculation of the long term variation of the variable cost with respect to time is similar to the previous one.

Considering  $P_i \forall i \in \{HS, LS, M, T, K\}$ ,  $Y$  and  $\tilde{k}_T$  fixed

$$\frac{d \ln Cvu_{LT}}{dt} = \frac{\partial \ln Cvu}{\partial t} + \frac{\partial \ln Cvu}{\partial \ln \frac{K}{Y}} \frac{d \ln \frac{K}{Y}}{dt}$$

We write the total differential considering  $Y$ ,  $\tilde{k}_T$  and  $P_i \forall i$  fixed,  $dP_K = \frac{\partial P_K}{\partial t} dt + \frac{\partial P_K}{\partial K} \frac{dK}{dt} dt = 0$

which leads to:

$$\frac{dK}{dt} = -\frac{\partial P_K / \partial t}{\partial P_K / \partial K}$$

$$\begin{aligned}
 \frac{\partial P_K}{\partial t} &= -\frac{\partial Y \frac{dCvu}{dK}}{\partial t} \\
 &= -Y \frac{\partial}{\partial t} \left( \frac{\partial Cvu}{\partial K} \right) \\
 &= -Y \frac{\partial}{\partial t} \left( \frac{Cvu}{K} \frac{\partial \ln Cvu}{\partial \ln K} \right) \\
 &= -\frac{Y}{K} \left[ \frac{\partial \ln Cvu}{\partial t} S_K^* \times Cvu + Cvu \frac{\partial S_K^*}{\partial \ln \tilde{k}_T} \right] \\
 &= -\frac{Y \times Cvu}{K} [\xi_t^* S_K^* + \alpha_{Kt}] \\
 &= \frac{P_K}{S_K^*} [S_K^* \xi_t^* + \alpha_{Kt}]
 \end{aligned}$$

$$\text{So } \frac{d \ln Cvu_{LT}}{dt} = \xi_t^* - S_K^* \times \frac{S_K^* \xi_t^* + \alpha_{Kt}}{S_K^* (S_K^* - 1) + \alpha_{KK}}$$

Then

$$\lambda^* = - \left( \frac{\partial \ln Cvu_{LT}}{\partial t} \right)_{LT} = - \left( \xi_t^* - S_K^* \times \frac{S_K^* \xi_t^* + \alpha_{Kt}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right) \quad (5.36)$$

### The long run externalities

We write the total differential considering  $Y$  and  $P_i \forall i$  fixed,  $dP_K = \frac{\partial P_K}{\partial \tilde{k}_T} d\tilde{k}_T + \frac{\partial P_K}{\partial K} \frac{dK}{d\tilde{k}_T} d\tilde{k}_T = 0$

wich lead to:

$$\begin{aligned}
 \frac{dK}{d\tilde{k}_T} &= -\frac{\partial P_K / \partial \tilde{k}_T}{\partial P_K / \partial K} \\
 \frac{\partial P_K}{\partial \tilde{k}_T} &= -\frac{\partial Y \frac{dCvu}{dK}}{\tilde{k}_T \partial \ln \tilde{k}_T} \\
 &= -\frac{Y}{\tilde{k}_T} \frac{\partial}{\partial \ln \tilde{k}_T} \left( \frac{\partial Cvu}{\partial K} \right) \\
 &= -\frac{Y}{\tilde{k}_T} \frac{\partial}{\partial \ln \tilde{k}_T} \left( \frac{Cvu}{K} \frac{\partial \ln Cvu}{\partial \ln K} \right) \\
 &= -\frac{Y}{\tilde{k}_T K} \left[ \frac{\partial Cvu}{\partial \ln \tilde{k}_T} S_K^* + Cvu \frac{\partial S_K^*}{\partial \ln \tilde{k}_T} \right] \\
 &= -\frac{Y \times Cvu}{\tilde{k}_T \times K} [\xi_{ET}^* S_K^* + \alpha_{KET}] \\
 &= -\frac{Y \times Cvu \times P_K}{\tilde{k}_T \times K \times P_K} [S_K^* \xi_{ET}^* + \alpha_{KET}] \\
 &= \frac{P_K}{\tilde{k}_T S_K^*} [S_K^* \xi_{ET}^* + \alpha_{KET}]
 \end{aligned}$$

$$\begin{aligned}
 \text{Then } \frac{dK}{d\tilde{k}_T} &= -\frac{\partial P_K / \partial \tilde{k}_T}{\partial P_K / \partial K} \\
 &= -\frac{P_K}{\tilde{k}_T} \left( \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^*} \right) / \frac{P_K}{K} \left( \frac{S_K^* (S_K^* - 1) + \alpha_{KK}}{S_K^*} \right) \\
 &= -\frac{K}{\tilde{k}_T} \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}}
 \end{aligned}$$

So, with  $Y$  and  $P_i \forall i$  fixed:

$$\frac{d \ln K}{d \ln \tilde{k}_T} = -\frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \quad (5.37)$$

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CHAPTER 5. FACTORS DEMAND IN ICT-RELATED INDUSTRIES

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Now we can calculate the impact of ICT capital externalities on the shares of variable factors with

$Y$  and  $P_i \forall i$  fixed:

$$\frac{S_i^*}{\tilde{k}_T} \frac{dS_i^*}{d\tilde{k}_T} = \frac{1}{S_i^*} \frac{dS_i^*}{d \ln \tilde{k}_T} = \frac{1}{S_i^*} \left[ \frac{\partial S_i^*}{\partial \ln \tilde{k}_T} + \frac{\partial S_i^*}{\partial \ln K} \frac{d \ln K}{d \ln \tilde{k}_T} \right]$$

Then

$$\frac{d \ln S_i^*}{d \ln \tilde{k}_T} = \frac{1}{S_i^*} \left[ \alpha_{iET} - \alpha_{iK} \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \right] \quad (5.38)$$

Moreover we have:

$$\begin{aligned} \frac{d \ln Cvu}{d \ln \tilde{k}_T} &= \frac{\partial \ln Cvu}{\partial \ln \tilde{k}_T} + \frac{\partial \ln Cvu}{\partial \ln K} \frac{d \ln K}{d \ln \tilde{k}_T} \\ &= \xi_{ET}^* - S_K^* \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \end{aligned} \quad (5.39)$$

So knowing that the optimal quantity,  $X_i^*$ , of the factor  $i$  can be written as  $X_i^* = \frac{S_i^* Cvu}{P_i}$ , we deduce:

$$\begin{aligned} \frac{d \ln X_i^*}{d \ln \tilde{k}_T} &= \frac{d \ln (S_i^* Cvu / P_i)}{d \ln \tilde{k}_T} \\ &= \frac{d \ln S_i^*}{d \ln \tilde{k}_T} + \frac{d \ln Cvu}{d \ln \tilde{k}_T} \\ &= \frac{S_i^* \xi_{ET}^* + \alpha_{iET}}{S_i^*} - \frac{S_K^* \xi_{ET}^* + \alpha_{KET}}{S_K^* (S_K^* - 1) + \alpha_{KK}} \left( S_K^* + \frac{\alpha_{iK}}{S_i^*} \right) \end{aligned}$$

Finally:

$$\frac{d \ln X_i^*}{d \ln \tilde{k}_T} = \frac{S_i^* \xi_{ET}^* + \alpha_{iET}}{S_i^*} - \frac{[S_i^* S_K^* + \alpha_{iK}] [S_K^* \xi_{ET}^* + \alpha_{KET}]}{S_i^* [S_K^* (S_K^* - 1) + \alpha_{KK}]} \quad (5.40)$$



## Part III

# ICT as an Enabling Technology





## Chapter 6

# How ICT become an engine of growth?

### 6.1 Introduction

The concept of a General Purpose Technology (GPT thereafter) and its relationship with innovation, productivity improvement and acceleration of economic growth offers an attractive conceptual tool to bridge the analysis of the micro-economic structures of technological change (innovational opportunities and complementarities) and the modeling of the macro-economic growth path. In examining the mechanisms through which a GPT in the shape of information technology has contributed to late twentieth-century economic growth, Bresnahan (2003 [32]) stresses that the phenomenon of socially increasing returns to scale that is manifested at the economy-wide level is based on the complementarity of various forms of innovative activity which crucially characterizes the production and diffusion of a GPT.

In their book, Lipsey, Carlaw and Bekar, (2006 [152]) give four essential characteristics defining a GPT that we reduced in three features in the general introduction. These are the peculiar properties of technical change that are crucial due to their centrality in explaining the complex relationship between innovation, productivity and economic growth at the macro-economic level. In the first part of this thesis we focused on the innovation rate in ICT and we showed that ICT verify the first GPT feature. In the second part we studied the second features showing the ubiquity of ICT and, in this third part

we will thus focus on the last feature: the technological complementarities.

Bresnahan and Trajtenberg (1995 [31]) define GPT as “enabling technologies” because they do not provide self-sufficient solutions but instead create large technological opportunities. Indeed, they insist on the potential of a GPT for broad applicability, horizontal propagation, and on the crucial complementarities between GPT’s inventions and the development of applications on the user’s side that will generate the general dynamics of the technology. The production of knowledge on the user side and the development of new applications, are crucial to ensure the effective diffusion of technology. This process is called the “co-invention of application” so as to stress the creative aspect of it. Expressed in other words, the successive inventions of a GPT extend the frontier of invention possibilities for the whole economy, while developments to its application change the production function of particular sectors. For example, the users of micro-electronics benefit from the technological advances in silicon by wrapping around the integrated circuits of their own technical advances.

Hence, the productivity of R&D in a user sector not only increases as a consequence of innovation in GPT but also because of the efforts of users themselves to “co-invent” similar applications. These phenomenon, called “innovation complementarities”, magnify the effects of innovation in the GPTs, and help propagate them throughout the economy.

The concept of co-invention is very general as it includes all developments that aim at exploiting the potential of the GPT: this may include new products integrating GPT as well as intangible innovations such as organization, training.... Hence these developments could be the consequence of either clearly identified R&D expenditure or of other expenditures such as reorganization, training or hiring qualified or specialized staff, that are brought together under the name of intangible investments (Brynjolfsson and Hitt, 2000 [38]; Brynjolfsson and Saunders, 2009 [40]; Bresnahan and Brynjolfsson, 2002 [33]).

Thus the full potential of a GPT can then only be exploited when these investments are installed and co-inventions developed, leading to a new “techno-economic paradigm” (Perez, 1983 and 1985 [183,184]; Freeman et al. 1982 [81]; Freeman and Soete, 1987 [85]; Freeman and Perez 1988 [185]) which serves to account for the lag between ICT investment and productivity growth as described before.

This section is organized as follows. The first part reviews the economic mechanisms linked to GPT and especially the externalities and the innovation complementarities inherent to such technologies. The second part defines the intangible investment and describes the way to evaluate it. It also reviews a new assessment of ICT impact in a growth accounting framework, taking into account the role of intangibles.

## 6.2 GPT as an enabling technology and engine of growth

The understanding of the mechanisms that drive technical progress is a crucial point for understanding the long term economic path. The theory of endogenous growth provides us with a framework with which to understand and evaluate long term growth via the endogenous decision of investment in R&D or in human capital. However, this theoretical stream better describes the long term steady state growth rather than the time path or the transition path. So, in this sense, it fails to truly explain transition movements and sectoral heterogeneities, due to the hypothesis of a homogenous technical progress. Then, when dealing with sectoral modelization, one needs to override this hypothesis that leads to a “long-sighted” approach (David, 1990 [67]), or to a too simplistic approach, because it does not take the real R&D sectoral interactions and inertia into account (Bresnahan and Trajtenberg, 1995 [31]).

As we mentioned in the introduction, some authors (David, 1990 [67]; Bresnahan and Trajtenberg, 1995 [31]; Freeman and Soete 1997 [86]; Helpman and Trajtenberg, 1998 [120]; Lipsey, Carlaw and Bekar, 2006 [152]) highlight the fact that periods of growth are driven by the deployment of certain technologies called General Purpose Technologies that induce increasing returns. These GPTs are mainly characterized by their pervasiveness and their ability to induce complementary investments and innovations.

As we shall see now, these properties allow us to explain certain dynamic features.

### 6.2.1 Innovation complementarities

The complementarities between GPT’s inventions and co-inventions of applications characterize GPT-producing sectors and GPT-using sectors as “strategic complements” as defined by Bulow et al. (1985 [41]) and they also initiate a virtuous circle in which advances in GPT lead to unpredictable inventions in their applications which, in turn, increase the return of further development in GPT.

The externality flows between the two types of sectors (inventors of the GPT and co-inventors of applications or in more simple words “producer and user”) is complex but important to understand in a detailed way. Bresnahan and Trajtenberg, 1995 [31] (and Bresnahan, 2003 [32]) described this structure with two categories of positive externalities that we schematize in graph 6.1:

1. Two vertical externalities (between inventors and co-inventors): innovation by inventors (respectively co-inventors) increases the returns from innovative activities for co-inventors (respectively

inventors). These externalities reflect innovational complementarities and reflect a problem of appropriability that runs both ways and thus corresponds to a bilateral moral hazard problem (Holmstrom, 1982 [121] and Tirole, 1994 [218]).

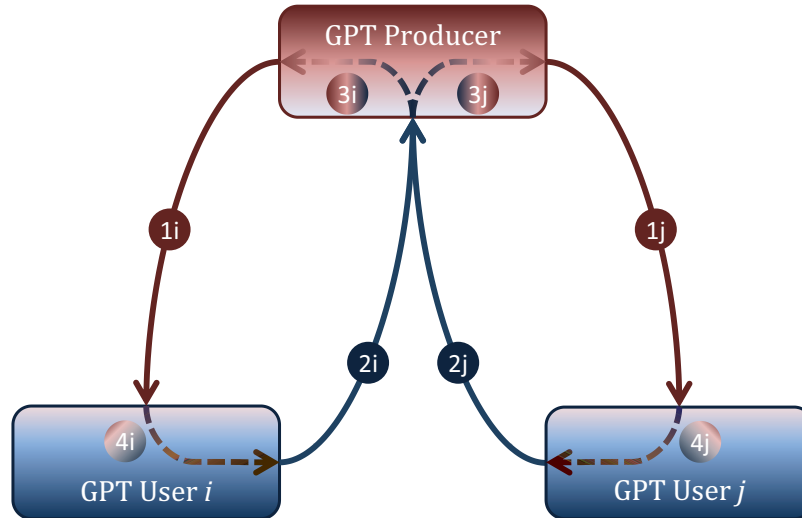
- (a) A first type of externality links the benefits of inventors of two complementary assets; the basic inventions generate new opportunities for developing applications in particular sectors (arrows  $1i$  and  $1j$ ).
  - (b) The second type describes the fact that the more extensive and earlier the co-invention and adoption in a user sector are, the higher the incentive for producers (basic inventors) to invest in R&D is. Application innovations increase the market for a GPT producer (arrows  $2i$  and  $2j$ ). However, we can define this phenomenon as an externality only if the GPT producers appropriate a part of the incremental surplus due to the application innovation.
2. The horizontal externality (between co-inventors) links the interests of the agents in the different application sectors. As co-inventors represent commercial opportunities, when there are more co-inventors their demands become larger leading to a higher level of investment in the GPT. These externalities induce a ripple effect in the ICT adoption and their level reflects the generality of the purpose of ICT. This externality appears within user sectors and deals with the increasing returns of innovation or the falling of co-invention costs: early user's experience lowers later cost of co-invention/adoption. In figure 6.1, 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  $i$  on user  $j$  by arrows  $2j-3i-1i$ .

This externality structure infers a lot of inertia in the system:

- When things evolve favorably, a long term dynamic appears that consists of large-scale investments in research and innovation whose social and private marginal rates of return attain high levels.
- In the other case, the system is likely to be trapped within a very low level of R&D in both types of sectors.

Actually, without coordination, inventors as well as co-inventors do not take into account either the externalities they generate on other sectors or their reactions in the future. For instance, when the GPT producer innovates, the incentive for a user to innovate is increased. However, as this user

Figure 6.1: GPT spillovers



does not take into account the feedback from his own externalities represented by the dotted arrows in the figure 6.1, his expectations are lower than the real expected returns of his R&D investments. Consequently, the level of his R&D investment will be lower than the optimum; moreover not only the private returns are lower than the public returns, but the private returns are also undervalued. The coordination between the GPT producer and the GPT user  $i$  is represented by the arrow  $3_i$  and  $4_i$  and the coordination between all stakeholders is intended to integrate all the reaction functions in the decision for the research effort of each member, thus highlighting the dynamic feedback loop in order to accelerate the sequential innovation process.

Therefore the lack of coordination creates logical lags at several levels:

- between invention and first co-invention;
- between co-invention and further investment in the basic invention;
- between early co-invention and the generalization of co-invented ideas.

According to Bresnahan and Trajtenberg, we can thus infer, with respect to these externalities, that the decentralized economy is, firstly, not efficient because of the independencies and uncoordinated transactions leading to too late and too small innovations and, secondly, because of the difficulties in forecasting technology.

### 6.2.2 “A time to sow and a time to reap”

Furthermore, from a dynamic point of view, Helpman and Trajtenberg (1994 [118], 1996 [119], 1998 [120]) show that externalities and the technological obsolescence of capital, resulting from the adoption of the new GPT, lead to a GPT deployment in two phases. The first phase is described as a “time to sow” where the resources are allocated to the development of complementarities of the inputs that benefit from the GPT. This period is characterized by slowdown of growth and wage stagnation. The second phase, defined by symmetry as the “time to reap”, occurs when the economy has developed enough complementarities and switches to the new GPT or to a more productive new techno-economic paradigm. This period is characterized by a high growth rate and an increase in wages. Between the two phases, in reality, a period could evince the temporal asymmetries reflected in “Baumol’s disease” in sectors that become more productive over others. For instance, the semiconductor leads to co-invention in electrical goods (hearing aids, radio, computer,...) before co-invention in services (online sales). Thus, the first type of sector which is already in the second phase pulls up the wages and induces an increase in costs leading to inflation in the second type of sector and finally generating the “Baumol’s disease”.

### 6.3 The case of ICT

In the theoretical framework, GPT are either exogenous or occur in a stochastic way, while in the analysis of the real economy, we need to identify the GPT that we must take into account. We could enumerate a number of technologies that have played a role of a GPT, although their importance varies, like power systems (steam, electricity), transport, organizational technologies (taylorism, mass production)... Moreover, the structural changes of the economy resulting from the adoption of these technologies are not totally separate and some of these technological revolutions were combined in history (electricity and mass production in the first half of the 20th century were strongly dependant for example). However we can identify the complementary links between the different GPT and establish a hierarchical classification (David and Wright, 1999 [68], 2003 [69]). In the most recent decades, the most prominent technologies to be defined as GPT are those known as “Information and Communication Technologies” (ICT). Indeed, most part of modern empirical studies around the theories of GPT is based on the analysis of the impact of ICT on the economy.

In other respects, this technology seems to meet the criteria defined by Bresnahan and Trajtenberg

## CHAPTER 6. HOW ICT BECOME AN ENGINE OF GROWTH?

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(1995 [31]) since, as we have seen in chapter 4, ICT are pervasive and technologically dynamic and, moreover, studies of the ICT impact seem to reveal potential complementarities. On one hand, the Solow paradox could be partly explained by the lack of complementary innovation, and, on the other hand, the cure for the Baumol's disease in the U.S. service sectors could also be accounted for through the development of complementary organizational innovation and the generalization of the productivity growth.

When we address the issue of complementary innovations or the development of applications, we first think of new product inventions. It is true that these innovations have been, and are still, highly visible and impressive in the field of ICT. Some examples consist of hearing aids (developed in 1953 which were one of the first applications of the transistor), the synthesizer, the robotics or, more recently, the mobile phone and the smartphone that have been developed, thanks to the miniaturization of processors and memory and also to the increasing possible communicable flows of information. However, they are not the sole possibilities of co-invention in the field of ICT. This perception of ICT co-invention may not only limit us in a too restrictive approach but may also be misleading in the sense that economic data on ICT described in chapter 4 are not necessarily compatible with this approach. In fact, the co-invention notion depends on the GPT's definition. For instance Bresnahan and Trajtenberg (1995 [31]), consider semiconductors as a GPT and thus, all industries that produce hearing heads, radio and TV or computers are defined as GPT users and co-inventors. In our case, and in the most recent studies that regard ICT as GPT, the definition of ICT is much larger than semiconductors and the frame of use is restricted:

- On one hand, as we saw in chapter 3, ICT goods and services include all goods and services that fulfil the function of information processing and communication including storage, transmission and display by electronic means<sup>1</sup>.
- On the other hand, the use of ICT is recognized only as an investment<sup>2</sup>.

Therefore, returning to the previous examples, the smartphone appears as an ICT good, thus it should not be defined as a co-invention but as an ICT innovation. Moreover, synthesizers or robotics do not appear in the ICT investment statistics since, as we explained before, the embedded electronic components are accounted for as intermediate consumption and are not identified as an ICT input

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<sup>1</sup>According to the container approach defined by OECD

<sup>2</sup>With separability conditions that we saw in chapter 3.



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on the side of the production of these goods, and, on the user side, they are not considered as ICT investment but as non-ICT investment<sup>3</sup>. Hence, if the robot improves the productivity of the “transport equipment” industry, it appears in the increase in non-ICT capital deepening or in MFP<sup>4</sup> of this sector but not in the increase of ICT capital deepening.

Nevertheless, there exists a large field of other complementarities, maybe less visible and less obvious, but probably as important as previous innovations. These co-inventions relate to the methods and organization of work whereas ICT basic inventions include all innovations that improve the transmission and processing of information, that is to say, principally, all innovations increasing the speed, the reliability and the protection of the transmission and processing of data.

As we have already explained, such innovations have already played a major role in the case of other GPT. The invention of the dynamo has reduced energy production costs, but the “power revolution” was in full swing when, in the 1920s, the unit drive system replaced the group drive system, thus allowing more precise control of the machinery required speed variations and especially their rearrangement and the application of the continuous production process (see Freeman and Soete 1997 [86], David, 1989 [66] and David and Wright, 2003 [69]). This new production organization led to mass production. Such radical changes are described more broadly as changes in “*techno-economic paradigm*” by Perez (1983 [183]).

Similarly, the diffusion of ICT today is leading to similar changes (Freeman and Louca, 2001 [82]). Evolutions of production modes are indeed already identified as consequences of ICT use, combined with organizational development such as lean production (Askenazy and Gianella, 2001 [9]). Thus, the “digital revolution” occurs, thanks to both ICT innovations and complementary innovations or practices.

The main issue that economists address is then the identification of the factors which contribute to the emergence of such innovations. Among other, Brynjolfsson and Hitt (2002 [37])<sup>5</sup> determine seven business practices that enhance productivity as the seven pillars of the digital organization in the sense that they lead to better performance and they are complementary to ICT adoption. These seven pillars are the following:

1. Move from analog to digital processes;

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<sup>3</sup>In case they are not used as final consumption.

<sup>4</sup>In fact it increases non-ICT capital deepening if the volume of capital is adjusted for quality otherwise it increases MFP.

<sup>5</sup>sum up in Brynjolfsson and Brown 2005 [35] or in Brynjolfsson and Saunders 2009 [40].

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2. Open information access;
3. Empower the employees;
4. Use performance-based incentives;
5. Invest in corporate culture;
6. Recruit the right people;
7. Invest in human capital.

Consequently, there are two ways to consider innovation complementarities. The first refers more to the complementarities of R&D while the second refers to complementarities in adopted technologies or practices. In the first case, two sectors benefit from complementary R&D when innovation from R&D in a sector increases the productivity of R&D in another sector and inversely. For instance, innovations in computing equipment increase the productivity of R&D in the machine equipment industry and innovations in machine equipment improve the productivity of the R&D in computing equipment.

In the second case, “two practices are complementary if the returns of adopting one practice are greater when the second practice is present. For example, the returns from adopting a certain computer system may be higher in the presence of training than in the absence of training, just as the returns from training may be higher in the presence of the computer system than in its absence.”<sup>6</sup>

In both cases, if we consider ICTs, the returns from the R&D in ICT are increased by the investment in R&D in other sectors and by the expenditures in organizational practices. And inversely, the returns from the expenditures in R&D and in organizational practices in all sectors are improved by the innovation in ICT. In other words, to reap the full benefits of ICT as a GPT, a firm must do more than buying new computers; it must, for instance, reorganize itself, do some training and/or undertake R&D. Moreover, the returns from reorganization or the R&D are greater if it adopts ICT. As we shall see in the next section, these elements, which are complementary to technical progress in ICT, are defined in the economic literature as intangible assets. So these complementary practices, which allow the full exploitation of ICT potential, consist in adopting ICT and investing in the intangibles. As, in the first part of this study, we focused on the adoption of ICT alone<sup>7</sup>, we will now direct our focus onto the other complementary asset: the intangibles.

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<sup>6</sup>Brynjolfsson and Saunders 2009 [40] referring to Athey and Stern (1998 [10])

<sup>7</sup>Within the limits of the statistical definition of ICT as an investment.

## 6.4 Intangible capital as a complementary asset of ICT

In the previous section, we discussed GPT properties and, in particular, we described the innovation complementarities that such technologies offer. We also noticed that these innovations must be understood in a broader sense as they may consist of inventions of new products as well as new work practices. Finally, we mentioned that the efforts undertaken in order to develop these complementary capabilities (such as expenditures in R&D, training or reorganization) can be assimilated as assets.

A number of studies incorporate the concept of intangible capital but, it is only recently that most of such studies focus on a few assets such as R&D or software. However, this approach still remains too restrictive, in the sense that it leaves out more than a half of total intangible assets. It neglects the largest part of organizational and human firm-specific capital which are all the more important to economic performance that organizational investments are highly complementary to technology investments.

So in this section, we define, more precisely, the notion of intangibles and we give plausible reasons to consider intangibles as capital. Then we describe the usual method to measure intangible investment and capital. Next, we proceed to an international comparison of the intensity of intangible investment and to a review of the early growth accounting studies that take into account intangibles.

### 6.4.1 Definition of intangible assets

There is still no widely and definitely accepted definition of intangible assets but, as the OECD report (2008 [169]) points out, all intangible asset identification attempts revolve around three main characteristics: i) they are viewed as sources of probable future economic profits; ii) they lack physical substance and iii) to some extent, they can be retained and traded by a firm. Thus, except for the fact that they have no physical substance, they still correspond to a wide definition of economic assets.

Black and Lynch (2005 [24]) propose a definition of organizational capital, despite being difficult to evaluate, comprising three components: workforce training, employee voice and work design. On the other hand, Corrado et al. (2005 [56], 2006 [57], 2009 [58]) establish a classification of intangible assets in three broad categories that are computerized information, innovative properties and economic competencies. These categories are described in table 6.1. This definition is certainly one of the most complete and is used in a large range of studies. According to this definition, the authors value the amount of investment in non-counted intangible assets in the same order of magnitude as the tangible

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ones (around \$1 trillion between 2000 and 2003 in US). Nakamura (2001 [163]) valued stocks to be worth roughly \$5 trillion in the US.

The statistical treatments of the different intangible classes are highly heterogeneous. The first category, computerized information, is already almost totally regarded as capital by accountants whereas in innovative property only a small part is capitalized and the economic competencies are totally neglected in capital accounting. Furthermore, the availability of data concerning the respective group of intangible assets is also unequal. Whereas databases exist that are relatively complete and homogeneous across countries for the two first groups, there are no reliable data concerning organizational capital. This propels economists to proceed using the indirect method to estimate investments and the stocks of intangible assets. We will enumerate some of these methods thereafter. Table 6.1 lists the different categories with their definitions and their current status in the U.S. National Income and Product Accounts, which are similar to their treatment in the other main national accounts.

As we will see, according to the estimations of Corrado et al. (2006 [57]), economic competencies account for almost half of the total intangible capital while computerized information accounts for roughly 15% in the United States. They also show that the NIPAs<sup>8</sup> series take into account less than 19% of all intangible capital. However, before discussing the measurement of intangible capital, in the next section, we sum up the arguments for capitalization of expenditure on intangible assets.

### 6.4.2 Why intangibles should be capitalized?

Corrado, Hulten and Sichel (2006 [57]) remind us that capital makes sense in an intertemporal context, given that it is a stock of wealth accumulated over time and that is used to produce new wealth. In other words, “any use of resources that reduces current consumption in order to increase it in the future qualifies as an investment” and all types of capital should be treated in the same manner. Traditionally, most economic studies identify capital only as physical assets such as machinery and equipment or buildings. In spite of this, R&D, training or organizational expenditures are, in fact, carried out for the purpose of future production. Thus, there is no reason to not treat them as investment. As such, intangibles should be defined as capital when they contribute towards future production.

Moreover, the choice made so far to consider intangibles as intermediate consumption is a convenient choice rather than a well-founded one. The argumentation is strongly linked to the measurement

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<sup>8</sup>National Income and Product Accounts

Table 6.1: Business intangibles, by group

Type	Definition	Current status in the NIPA
<b>1. Computerized information</b>	Includes business investment in software (purchases and own-account components) and computerized databases	Major components are capitalized
<b>2. Innovative property</b>		
a. Scientific R&D	Includes costs of new products and new production processes, usually leading to a patent or license	Most spending is expense (only oil and gas exploration and architectural and engineering services embedded in structures and equipment purchases, are included in business fixed investment)
b. Non-scientific R&D	Includes mineral exploration, copyright and license costs and other development, design and research expenses (not necessarily leading to a patent or copyright)	
<b>3. Economic competencies</b>		
a. Brand equity	Includes advertising expenditure and market research for the development of brands and trademarks	No items recognized as assets of the firm
b. Firm-specific resources	Includes human capital: costs of developing workforce skills, i.e. on-the-job training and tuition payments for job-related education; and organizational structure: costs of organizational change and development, company formation expenses	

Source: Corrado et al. (2005 [56] and 2006 [57])

difficulties that characterize this type of asset. Corrado et al. 2006 [57] identify these difficulties as (i) the *lack of verifiability*, especially because intangibles are often produced within the firm and, because of this, the prices are difficult to determine, (ii) the *lack of visibility*, by definition since they are intangible, (iii) the *non-rivalness* and (iv) the *lack of appropriability* of the returns of some intangibles, since knowledge produced by an agent could benefit another without a market transaction and without diminishing the quantity available to the former. It is therefore clear that all these characteristics of intangible assets make their quantification difficult, but, it does not justify the choice to treat them as intermediate consumption, especially since it impacts our economic assessments and obscures the large role played by these factors in the “new economy”. Indeed, to take into account intangibles in growth accounting models changes both the output growth and the respective contribution of factors. It is, then, necessary to respect the symmetry principle in the treatment of capital. Furthermore, the externalities induced by the non-appropriation of intangible investment manifests itself by increasing the MFP if we do not raise the level of intangible capital by the amount of the externalities (Hulten, 2001 [122])

Admittedly, software is now considered as capital by most accountants and R&D will soon be considered as capital too, but it is not sufficient with regards to the size and the evolution of its other components. The effort should, then, focus on the census or the assessment of the data on intangible accumulation and for now, a rough estimate is better than overlooking these factors.

In the next paragraph, we will describe the different methods used to assess the amount of investment and capital in intangible assets.

### 6.4.3 Intangible capital: Another measurement challenge

#### 6.4.3.1 Estimation methods of organizational capital

Both the intangible nature of these assets and the fact that they can either be purchased or developed means their quantification is difficult because of the problems raised above. Three general methods are referenced by Brynjolfsson and Saunders (2009 [40]) and by Sichel (2008 [208])<sup>9</sup>. The first methodology is based on direct expenditure data, the second on financial market valuation and the third on other performance measures.

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<sup>9</sup>Hunter et al. (2005 [123]) also made a review of practices to measure intangible capital.

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**The direct expenditure based approach** consists of measuring the spending on some categories of assets identified as intangible, making an assumption on the proportion of intangible expenditures to be capitalized. Nakamura (2001 [163], 2003 [164]) first used this method in the U.S. and identified four broad categories of expenditures as intangible investment: R&D, Advertising, Software and others (such as compensation and salaries of managers and creative professionals). He estimated the amount of intangible investment within a range of US\$700 billion and US\$1.5 trillion, which is in the same order of magnitude as non-residential tangible investment, and the intangible capital stock as around US\$5 trillion. More recently, Corrado et al., 2005 [56], 2006 [57] developed this method and slightly expanded the definition of intangible investment to those enumerated above (see table 6.1). They also find that the level of business fixed investment in intangibles may have been as large as spending on tangible capital and that a significant part of this amount is excluded from the national account of investment. Other economists have later applied this method to other countries, such as Hao et al. (2008 [113]) and Van Ark et al. (2009 [225]) to several European countries, Marrano, Haskel and Wallis (2009 [155]) to United Kingdom, van Rooijen-Horsten et al. (2008 [232]) to the Netherlands, Jalava et al. (2007 [129]) to Finland and Fukao et al (2009 [87]) to Japan.

**The financial market based approach** is a more indirect method than the previous one and is based on the assumption that the value of intangible capital is the value of the difference between the total market value of firms and the value of firms tangible assets. This method was especially adopted by Hall (2001 [112]) or Brynjolfsson, Hitt and Yang (2002 [39]) for U.S.. Webster (2000 [235]) adopted this approach for Australia as well as the World Bank (2006 [13]) which deduced the value of intangible capital from the difference between total wealth<sup>10</sup> and natural and produced capital, at the country level.

**The “other performance” based approach** Instead of market values, which are particularly unstable and subject to speculative bubble in IT related industries, this approach uses analysts’ forecasts of firm’s earnings and their stock market value to construct the value of intangibles. This type of approach is used by Cummins (2005 [61]) or Lev and Radhakrishnan (2005 [151]) in order to evaluate organizational capital. They find a level of organizational capital worth around 4% of the income for their sample of US firms.

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<sup>10</sup>Defined as the net present value of future sustainable consumption

We can also mention other methods, for example one which consists of polling firms directly, “asking firms how much they invest in training, organizational change and other intangible complements when they install or upgrade technology” (Brynjolfsson, Fitoussi and Hitt, 2005 [36] adopted this method, see Brynjolfsson and Saunders 2009 [40]). However, acknowledging the fact that most recent studies have applied the source of growth model using data constructed from the direct expenditure approach, we will pay a particular attention to the data based on this method.

### 6.4.3.2 Intangible investment deflators and intangible capital stock construction

As we did for ICT investment, we need to define a price deflator to convert nominal values to their real counterparts in order to construct the intangible capital stock. In section 3.3, we saw that this is one of the most difficult empirical issues in the evaluation of ICT, especially because of the quality adjustment. Concerning intangibles, this is also a very difficult task particularly so due to the lack of verifiability and visibility already mentioned and described in Corrado et al. (2006 [57]). Indeed Cummins (2005 [61]) assumes “that intangibles are nearly impossible to value as stand-alones. In particular, intangibles have unobservable shadow prices that depend on expectations. This setup makes the return on intangibles impossible to measure directly and uncertain by construction.” In practice, depending on the asset, the methods are the following.

For computerized information, especially for software, the most commonly used price deflator is described above in section 3.3. Traditionally for R&D, the method used in the literature is the one developed by Jaffe (1972 [128]) and Griliches (1984 [100]) based on input costs. “The most common approach has been to take the average of a wage deflator and a price deflator for a broad measure of output on the grounds that R&D expenditures are roughly 50 percent labor costs and 50 percent supplies” (Corrado et al., 2009 [58]). Some only use the wage deflator. However Corrado et al. (2009) find this latest approach irrelevant for intangibles because it supposes that labour and, eventually, intermediate consumption are the sole inputs in the production of intangibles (especially as it does not need capital) and that the growth rate of MFP in this production is null. Thus, they opt for a pure output deflator as a proxy for the price of intangibles and they “adopt the non-firm business output price deflator as a proxy for intangible investment price deflator. This proxy can be rationalized by the fact that much R&D and coinvestments in marketing and human competencies are tied to specific product lines. Integrating the cost of productivity-enhancing investments back into the “using” industries is



Table 6.2: Depreciation rates for intangible capital stock

<b>Assets</b>	<b>Depreciation rates</b>
Computerized information	0.33*
Innovative property	0.20
Economic competencies	
Brand equity	0.60
Firm-specific human capital	0.40

\*0.315 in Van Ark et al. [225] which used EU KLEMS

Sources: *Corrado, Hulten and Sichel (2006 [57])*

generally accomplished by adopting the non-farm business output price as the deflator for intangibles.” This latter approach is used in most studies for the construction of intangible capital series, except for computerized information assets.

Finally, in order to construct the capital stock, the depreciation rates that are commonly used are given in table 6.2. Economic competencies are the assets that depreciate the most, with depreciation rates ranging between 0.4 and 0.6, whereas the depreciation rate of innovative property assets is only 0.2.

## 6.5 Intangible capital: an international comparison

### 6.5.1 Intangible capital investment accross countries

Nowadays, many authors are becoming interested in the evaluation of intangibles in many countries; among them, we can mention the following: Corrado, Hulten and Sichel (2005 [56]) for U.S.; Marrano, Haskel and Wallis (2009 [155]) for United Kingdom; Hao, Manole, Van Ark (2008 [113]) for France, Germany, Spain and Italy; to which Van Ark, Hao, Corrado, Hulten (2009 [225]) add Austria, Czech Republic, Denmark, Greece and Slovakia; van Rooijen-Horsten et al. (2008 [232]) for the Netherlands; Jalava, Aulin-Ahmavaara and Alanen (2007 [129]) for Finland; Van Ark and Hulten (2007 [226]) for Sweden and Fukao et al. (2009 [87]) for Japan. Moreover, in addition to these articles we can also consider the European project INNODRIVE<sup>11</sup> which has led to the construction of a database on intangibles for European countries on a macro-level. (see Piekkola 2011 [186])

From these quantifications of intangible capital in different countries, we can deduce the following

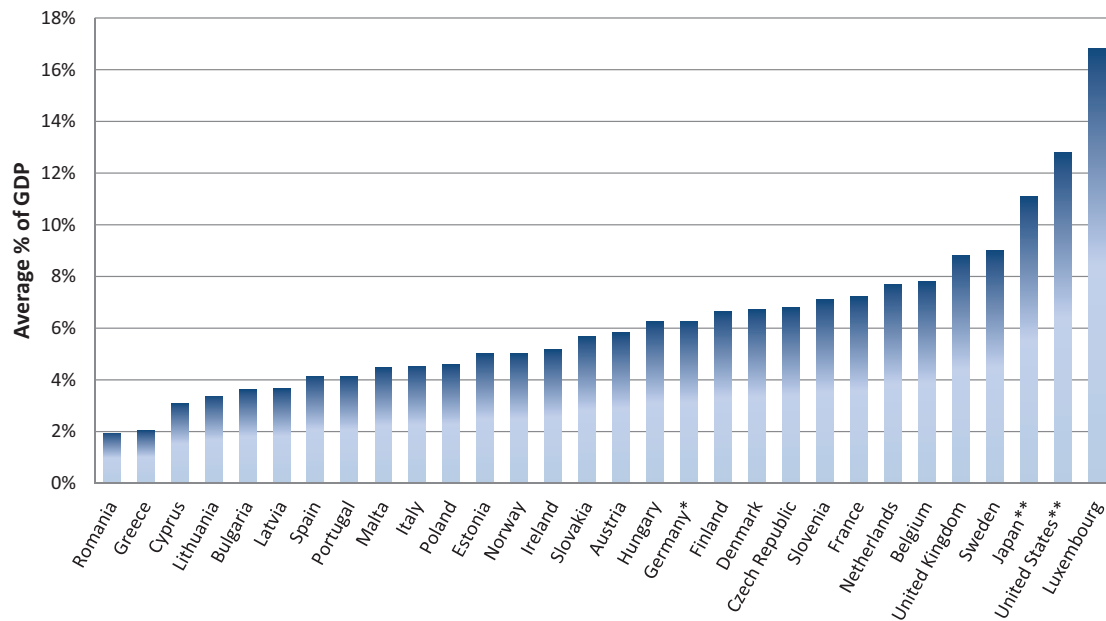
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<sup>11</sup>Intangible Capital and Innovations: Drivers of Growth and Location in the EU; [www.innodrive.org](http://www.innodrive.org), EU Seventh Framework Programme.

three important observations:

- Firstly, the intangible investment intensity, measured by the ratio intangible investment / GDP, is heterogeneous among countries. Furthermore, it is noteworthy that, as we can see in figure 6.2, in all European countries (except Luxembourg) the average intangible intensity, over the ten years 1995-2005, is lower than in the U.S. and Japan. This average intangible intensity is also strongly heterogeneous between European countries, ranging from less than 2% for Romania and Greece to roughly 8,5% of GDP for United Kingdom and Sweden. Among their sample, Hao et al. (2008 [113]) and Van Ark et al. (2009 [225]) show that only the U.S. and the U.K. spend more on intangible than on tangible investment.
- Secondly, there are also differences in the composition of intangible assets between countries that could reflect the sectoral composition heterogeneity across countries (see table 6.3). For instance, the U.K. shows a high share in “economic competencies” which should reflect the large share of business services there.
- Thirdly, in a dynamic perspective, Van Ark et al. (2009 [225]) observe that intangible investment rates are relatively stagnating in the biggest European countries such as France, Germany or U.K. but are on an upward trend in some smaller countries and, especially, in Denmark and Austria.

Figure 6.2: Average intangible investment rate from 1995-2005



\*including ex-GDR from 1991

\*\*Average during 1995-2007 for United States and during 2000-2005 for Japan; This might overestimate the U.S. and Japanese shares with respect to the other countries but their relative position should remain unchanged.

Sources: *INNODRIVE* database release May 2011 for European countries; Corrado & Hulten (2010 [59]) for U.S.; Fukao et al. (2009 [87]) for Japan

Table 6.3: Intangible composition (Shares in total intangible investment in %)

Type of investment	US 2006	Japan 2000-05	UK 2006	France 2006	Denmark 2006	Germany 2006	Austria 2006	Italy 2006	Spain 2006
<b>1. Computerized information</b>	<b>14.02%</b>	<b>19.82%</b>	<b>14.69%</b>	<b>17.97%</b>	<b>23.79%</b>	<b>10.20%</b>	<b>13.80%</b>	<b>12.70%</b>	<b>14.44%</b>
a) Software	-	18.02%	-	17.34%	23.54%	9.92%	13.18%	12.50%	13.89%
b) Databases	-	1.80%	-	0.63%	0.38%	0.28%	0.62%	0.20%	0.55%
<b>2. Innovative property</b>	<b>38.07%</b>	<b>54.05%</b>	<b>29.95%</b>	<b>40.25%</b>	<b>38.93%</b>	<b>50.14%</b>	<b>48.68%</b>	<b>43.85%</b>	<b>50.82%</b>
a) R&D, incl. social and human.	19.60%	25.23%	10.14%	16.46%	21.37%	24.02%	26.98%	11.51%	11.52%
b) Mineral exploration	0.00%	0.38%	0.38%	0.51%	0.00%	0.14%	0.00%	1.79%	0.73%
c) Copyright and license costs	9.91%	9.91%	2.09%	3.92%	2.04%	2.93%	1.55%	1.98%	3.29%
d) Development costs in fin. ind.	18.47%	18.02%	0.66%	7.59%	6.87%	10.47%	9.77%	11.51%	9.51%
e) Archi. & engineering designs	47.91%	26.13%	55.36%	41.77%	8.78%	12.57%	10.23%	17.06%	25.78%
<b>3. Economic competencies</b>	<b>47.91%</b>	<b>26.13%</b>	<b>55.36%</b>	<b>41.77%</b>	<b>37.28%</b>	<b>39.66%</b>	<b>37.52%</b>	<b>43.45%</b>	<b>34.73%</b>
a) Brand equity	12.80%	10.81%	10.90%	12.53%	8.02%	7.82%	3.88%	14.09%	7.68%
Advertising expenditure	-	-	8.63%	9.24%	4.58%	5.73%	2.33%	9.33%	3.47%
Market research	-	-	2.27%	4.56%	3.44%	2.09%	1.71%	4.76%	4.20%
b) Firm-specific human capital	-	4.50%	24.08%	19.11%	18.96%	18.02%	12.25%	20.24%	14.81%
Continuing vocational training	-	-	-	15.82%	13.61%	9.08%	7.13%	14.09%	12.98%
Apprentice training	35.10%	-	-	3.29%	5.34%	8.94%	5.12%	6.35%	1.83%
c) Organizational structure	-	10.81%	20.28%	10.25%	10.31%	13.97%	21.40%	8.93%	12.43%
Purchased	-	-	4.83%	4.05%	5.73%	7.54%	14.42%	2.98%	4.94%
Own account	-	-	15.45%	6.20%	4.58%	6.42%	6.82%	5.95%	7.50%
<b>Total Investment</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>

Sources: Calculus from Fukao et al. (2009, [87]) for Japan and from Van Ark et al. (2009 [225]) for other countries

### 6.5.2 Intangible capital in a Growth Accounting Framework

Box 6.5.2: The Corrado, Hulten and Sichel (CHS) Source Of Growth (SOG) model (1/2)

The aim of the SOG framework is to allocate the growth rate of output to the share weighted growth rates of the inputs plus a residual.

In order to understand the impact of the inclusion of intangible assets in growth accounting, CHS (2006) compare the two calculations:

We consider a world with three goods: consumption  $C$ , tangible investment  $I$  and intangible  $N$  and we note  $L$  the labor,  $K$  the tangible capital and  $R$  the intangible capital.  $P^X$  represents the price of the input or output  $X$ .  $P^K$  and  $P^R$  are the user costs associated with the services of respectively the tangible capital and the intangible capital.

1. In a conventional SOG model, where intangibles are treated as an intermediate good, the GDP identity has the following form:

$$P^{Q'}(t)Q'(t) = P^C(t)C(t) + P^I(t)I(t) = P^{Q'}(t)A'(t)f'(L(t), K(t))$$

according to Solow (1957 [212]) we obtain the SOG equation:

$$g_{Q'}(t) = s'_C(t)g_C(t) + s'_I(t)g_I(t) = s'_L(t)g_L(t) + s'_K(t)g_K(t) + g_{A'}(t)$$

where  $s'_x(t) = P^x(t)x(t) / \sum_{input\ or\ output} P^u(t)u(t)$  is the share of the output or the input in value and  $g_{x'}(t)$  is the rate of growth of the variable  $x$ ;  $g_{A'}(t)$  denote the growth rate of multifactor productivity.

2. In the CHS growth accounting model, where intangibles are capitalized, the GDP identity is defined as followed:

$$P^Q(t)Q(t) = P^C(t)C(t) + P^I(t)I(t) + P^N(t)N(t) = P^{Q'}(t)A(t)f(L(t), K(t), R(t))$$

now the SOG equation takes the form:

$$g_Q(t) = s_C(t)g_C(t) + s_I(t)g_I(t) + s_N(t)g_N(t) = s_L(t)g_L(t) + s_K(t)g_K(t) + s_R(t)g_R(t) + g_A(t)$$

Box 6.5.2: The Corrado, Hulten and Sichel (CHS) Source Of Growth (SOG) model (2/2)

The comparison of the two results reveals two things:

1. The GDP growth rate increases with the inclusion of intangibles as capital if  $g_N(t) > g_{Q'}(t)$  and decreases if  $g_N(t) < g_{Q'}(t)$ .
2. The contribution of labor and tangible capital are reduced from a factor of proportionality  $\lambda = \frac{P^L L + P^K K}{P^L L + P^K K + P^R R}$  since  $s_L(t) = \lambda s'_L(t)$  and  $s_K(t) = \lambda s'_K(t)$ ; We can note that in the case of the Golden Rule steady state we also have  $g_A(t) = \lambda g_{A'}(t)$ , the relation is notwithstanding more complicated in other cases.

Using the databases they constructed, many of these authors assessed the impact of the intangibles on economic and productivity growth using a growth accounting framework and using the same methodology we used in chapter 4 for the evaluation of the impact of ICT capital. In particular, they used a new source of growth (SOG) model of the type described in the box 6.5.2 including intangibles, and as well as for ICT, these studies are conclusive and strongly consistent. We sum up, here, the key effects of the inclusion of intangibles as capital within a growth accounting framework.

The first important consequence is that accounting for intangible expenditures as investment rather than intermediate consumption increases, de facto, the level of GDP, since intangibles as intermediate consumption do not appear in GDP whereas that would have been accounted for if they had been defined as investment (Corrado, Hulten and Sichel 2006 [57] or 2009 [58]) This is explained in box 6.5.2. Marrano et al. (2009 [155]), who evaluate the impact of knowledge spending as investment in U.K. between 1970 and 2004 estimate that the market sector gross value added (MGVA) in this country was understated by about 6% in 1970 and 13% in 2004. Hao et al. (2008 [113]) and Van Ark et al. (2009 [225]) find that, taking into account intangibles increases the GDP level of the amount of intangible investment rates, which range between 1.59% and 11.69% of GDP, conventionally measured according to the country in their sample. Furthermore, since intangibles grow rapidly, the rate of growth of the GDP is also increased. Van Ark et al. (2009 [225]) assess an increase of GDP growth rates of about 0.1 - 0.2 percentage points between 1995 and 2006 for the countries they study.

A second direct effect is that it induces an increase in the share of Gross Domestic Income (GDI) accruing to capital (tangible and intangible) and a lower share for labor income. Corrado et al. (2006 [57]) find that it decreases the share of income accruing to labour from about 70% to 60% and

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conversely it increases the share of capital income from about 30% to 40% (the share of intangible accounting for 37.5% of all capital income). In a dynamic perspective, they observe that the income labour share decreases over time. Obviously there is a fallout on the concept of saving rates since, as these authors point out: “the consumption rate is smaller and the rate of saving/investment is correspondingly higher.” They also note that “this result is relevant in view of a low rate of saving in the U.S. economy, particularly because existing measures exclude much of the investment in knowledge capital that is a defining feature of the modern U.S. economy”.

The analysis of the results of the new SOG models including intangibles with respect to previous studies without intangibles leads to the following findings: taking into account intangible capital changes both the growth rates of output and productivity and also the shares of the respective contribution of each factor to output and productivity growth. Moreover, given that the accumulation of intangible capital has considerably accelerated recently, the inclusion of intangibles has growing importance. (In table 6.4 we provide the results obtained in Van Ark et al. (2009 [225]).

Corrado et al. (2009 [58]) estimate that intangible capital which is not measured in traditional statistics, contributed to 0.57 percentage points (18.4%) in labour productivity growth in U.S. during the 1995-2003 period and the inclusion of intangibles as capital increases the importance of the factors typically associated with the growth of “knowledge economy”. The comparison between the SOG model with intangibles and those without intangibles for the periods 1973-1995 and 1995-2003 shows, according to their results for the U.S., that the inclusion of intangibles:

1. Induces a higher growth rate of labour productivity in both periods if we include intangibles but especially in the first period of 1973-1995;
2. Changes the relative importance of factors “explaining” growth:
  - (a) Increases the weight of capital deepening (from 44% to 59% during 1973-1995 and from 35 to 54% during 1995-2003),
  - (b) Reduces the MFP contribution to labour productivity growth (from 1.42% to 1.08% between 1995-2003);
3. Has no impact on the relative acceleration of labour productivity observed between the two periods but changes the sources of this acceleration, decreasing the contribution of MFP and increasing the contribution of capital deepening.

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More specifically, concerning the last point, they find that the two most important intangible factors in this acceleration are computerized information (0.15%points) and firm-specific resources (0.14%points) whereas scientific R&D does not account for a large part. Finally, they point out that the part of intangibles which is not included in national accounts (non scientific R&D, brand equity and firm-specific resources) represents nearly 60% of total intangible capital deepening.

Oliner, Sichel, Stiroh (2008 [174]) extend the series on intangibles for U.S. evaluated by Corrado et al. and use an extension of the growth accounting framework that melds the original Oliner-Sichel model (2000 [171], 2002 [172]) with the model of Basu et al. (2004 [14]) that takes into account intangible capital<sup>12</sup>. They find some differences with their previous results<sup>13</sup> after including intangibles; especially, a stronger growth rate in labor productivity during the period 1995-2000 but a lower growth rate between 2000 and 2006. This reflects the complementarity between ICT and intangible capital. Indeed, “the real intangible investments have surged during 1995-2000, boosting growth in aggregate output, and then retreated during 2000-2006.” Moreover, they find a lower contribution of MFP after 2000 but a higher contribution during 1995-2000 and, contrary to the previous results, the increase of the MFP contribution between the two periods 1995-2000 and 2000-2006 is negligible.

In the same way, Marrano et al. (2009 [155]) find for the U.K. that growth in labor productivity and capital deepening has been understated and growth in MFP overstated over the period 1973-2004. However, unlike in the US, they find that MFP growth has been accelerating since 1990. In Japan, Fukao et al. (2009 [87]) estimate that the inclusion of intangibles increases the output growth rate until 2000 and reduces it between 2000-2005. However the labour productivity is higher in 1985-1990 and 1995-2000 but lower in 1990-1995 and 2000-2005. In addition, they affirm that taking into account intangibles has a positive impact on capital deepening and a negative impact on MFP except during 1995-2000.

On the European side, Jona-Lasinio et al. (2011 [131]) show that, after the inclusion of intangibles, labour productivity growth increases for all countries except for Sweden. Furthermore the contribution of capital deepening is enhanced, between 0.20 and 0.24% points for Denmark, France, Germany, the Netherlands and the U.K., and becomes the main source of growth during the period 1995-2005 in all countries except in Italy and Spain which lag behind in intangibles and see a negligible impact on

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<sup>12</sup>They use the intangible capital estimated by the Corrado, Hulten and Sichel, 2005, 2006 [56] [57] specification. And, in order to extend the intangible series they assume that the intangible capital is complementary to the ICT capital. Despite the ICT complementarity, the investment in intangible capital increases less than the ICT investment for the whole period because of a less decline of their price with respect to the ICT goods.

<sup>13</sup>The previous results were described in section 4.



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their capital deepening. They also show that the intangible capital deepening contribution is more important than the tangible capital<sup>14</sup> deepening contribution in three countries: France, Denmark and Finland. Van Ark et al. (2009 [225]) assess the contribution of intangible capital to labour productivity growth as a range of 10 to 40% of all input contributions according to the country. In other respects, we note that the impact of the inclusion of intangibles depends on the business cycle and more precisely it appears to be positive over the period 1995-2000 but negative over the period 2000-2005. Nevertheless, further research is needed to better understand these findings.

Otherwise, the impact varies greatly from one country to another. First, the nature of the impact is different according to the country, since the relative impact on capital deepening and MFP growth is heterogeneous among countries. For instance, Jona-Lasinio et al. (2011 [131]) find that the inclusion of intangibles has a strong positive effect on capital deepening in Sweden but not on labour productivity, reflecting a strong decrease in MFP growth. Conversely, for Austria, they observe a strong increase in capital deepening associated with a strong increase in labour productivity growth and thus a reduction in MFP growth that is relatively small. Secondly, the impact is heterogeneous in magnitude. Van Ark et al. (2009 [225]) identify four groups of countries:

1. US and UK, which show rapid labour productivity growth and high contributions of intangibles;
2. France, Denmark, Germany and Austria, which still show significant contributions against the backdrop of smaller growth rates of labour productivity;
3. Catching-up countries such as the Czech Republic and Greece (and also Slovakia) which show much larger contributions from non-ICT-capital deepening than from intangibles, and – in some cases – also larger MFP growth rates related to the restructuring of these economies;
4. And laggard economies, such as Italy and Spain, which show small absolute contributions of intangibles coupled with slow growth in labour productivity and even negative contributions from MFP growth.

Then, they draw a stylized fact from the analysis of their results: “Intangible investment intensity is correlated with the level of economic development, whether measured by per-capita income or hourly labour productivity”. In addition, Jona-Lasinio et al. (2011 [131]) note that, on one hand, the two countries with the most intangible intensive economies, Sweden and United Kingdom, belong to the

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<sup>14</sup>Here tangible capital includes Non-ICT tangible capital and ICT capital without software.

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group of the three faster growing countries and, on the other hand, the two laggard countries in terms of intangible intensity, Italy and Spain, are also the two slowest growing countries in their sample. They add that in the three fastest growing countries: Sweden, Finland and U.K., the main source of growth is R&D capital deepening for the two first and organization capital for the U.K..

Finally Van Ark et al. (2009 [225]) find a strong correlation between intangible capital deepening and MFP, highlighting the probable existence of spillovers from intangibles.

In conclusion, taking into account intangible expenditure as investment enabled economists to clarify some points:

- Firstly, as Corrado et al. (2009 [58]) showed, the jump in productivity growth that took place after 1995 has no effect in amplitude but better explained in the sense that the inclusion of intangibles reduces the weight of MFP, which include all that we do not take into account, in productivity acceleration<sup>15</sup>. In this way, intangibles as capital partly explain the “*productivity paradox*” revealed by Solow.
- Secondly, the other apparent paradox of the continued productivity acceleration that occurs after 2000 despite the sharp drop in ICT investment, disappears. Productivity growth does not increase in the U.S. after 2000 with the inclusion of intangible capital in the SOG model (Oliner et al., 2008 [174]).
- Thirdly, it reduces the role of MFP in the labour productivity growth during the decade beginning in 1995 and decreases the share of MFP in the differences between countries<sup>16</sup>; thus, intangibles, in addition to ICT, should be an important factor of economic development.

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<sup>15</sup>Oliner Sichel and Stiroh (2008 [174]) do not obtain these results, however they compare SOG with tangibles and SOG without intangibles including software whereas Corrado et al. exclude software.

<sup>16</sup>The standard deviation between countries decreases more for MFP than for labour productivity in table 6.4

Table 6.4: Average annual change in labour productivity and contributions during 1995–2006\*

	US	UK	FR	DK	DE	AT	CZ	GR	SL	IT	SP
<b>1. Conventional Growth Accounting</b>											
<b>Labour productivity growth</b>	<b>2.75</b>	<b>2.90</b>	<b>1.83</b>	<b>1.54</b>	<b>1.61</b>	<b>1.99</b>	<b>4.50</b>	<b>3.21</b>	<b>6.30</b>	<b>0.26</b>	<b>0.36</b>
Contributions											
ICT capital deepening	0.47	0.74	0.14	0.50	0.23	0.29	0.38	0.46	2.85	0.12	0.21
Non-ICT capital deepening	0.30	0.36	0.37	0.28	0.57	-0.03	1.76	1.52	0.49	0.31	0.56
Labour quality	0.20	0.26	0.44	0.19	-0.16	0.24	0.34	0.73	0.24	0.24	0.68
MFP	1.78	1.54	0.88	0.57	0.98	1.49	2.02	0.51	2.97	-0.41	-1.10
<b>2. Growth Accounting Including Intangibles</b>											
<b>Labour productivity growth</b>	<b>2.96</b>	<b>3.06</b>	<b>2.00</b>	<b>2.11</b>	<b>1.79</b>	<b>2.36</b>	<b>4.60</b>	<b>3.27</b>	<b>6.17</b>	<b>0.29</b>	<b>0.47</b>
Contributions											
ICT capital deepening	0.40	0.63	0.12	0.44	0.20	0.26	0.35	0.45	2.72	0.11	0.19
Non-ICT capital deepening	0.24	0.28	0.31	0.24	0.48	-0.02	1.62	1.48	0.21	0.29	0.49
Intangible capital deepening	0.83	0.69	0.48	0.72	0.38	0.55	0.68	0.24	0.21	0.12	0.12
<i>Computerized information</i>	<i>0.18</i>	<i>0.16</i>	<i>0.15</i>	<i>0.29</i>	<i>0.07</i>	<i>0.13</i>	<i>0.06</i>	<i>0.06</i>	<i>0.04</i>	<i>0.03</i>	<i>0.05</i>
<i>Innovative property</i>	<i>0.35</i>	<i>0.17</i>	<i>0.18</i>	<i>0.27</i>	<i>0.23</i>	<i>0.29</i>	<i>0.35</i>	<i>0.11</i>	<i>0.07</i>	<i>0.05</i>	<i>0.15</i>
<i>Economic competency</i>	<i>0.29</i>	<i>0.36</i>	<i>0.15</i>	<i>0.17</i>	<i>0.07</i>	<i>0.13</i>	<i>0.27</i>	<i>0.07</i>	<i>0.10</i>	<i>0.04</i>	<i>-0.08</i>
Labour quality	0.18	0.22	0.40	0.17	-0.15	0.22	0.31	0.71	0.46	0.22	0.64
MFP	1.33	1.23	0.69	0.53	0.88	1.35	1.64	0.40	2.78	-0.45	-0.96

\*Except for Czech Republic: 1997–2006 and for Slovakia: 2000–2006

Source: Van Ark et al. (2009 [225])

## 6.6 Conclusion

The recognition of ICT as a General Purpose Technology leads us to take into account some key mechanisms. In particular, the enabling nature of such technologies means that their economic strength lies in their ability to create opportunities for complementary innovations in user sectors. As a result, the economic theories on GPT show that ICT innovations and diffusion alone are insufficient to support economic growth and need further complementary investments in order to develop co-inventions. Such co-inventions could result in a new production mode, i.e. a new techno-economic paradigm.

In fact, in the case of ICT, a consensus is forming with the idea that complementary efforts take the form of research both in new products and services and in new organization. Furthermore, these efforts are reflected by the expenditures in intangible assets.

However, until now, national accounts ignore most of intangible capital, and this influences our perception of both economic growth and its sources. In addition, this convention not only has no rational justification but it also leads us to omit some features of the economic evolution over the recent decades. Indeed, as showed by recent studies on the sources of productivity growth, the apparent paradox of the productivity resurgence in the US after 2000 seems to be accounted for by the inclusion of intangible capital in growth accounting. Intangible capitalization also helps to account for some differences in economic performances across countries.

In the following chapter, we will proceed with a similar assessment for European countries in order to highlight the role of both ICT and intangible capital in their recent productivity growth whereas in the chapter 8, we aim to estimate the complementarities between these two assets.



## Chapter 7

# What specificities for European countries?

### 7.1 Introduction

This chapter analyses the sources of labor productivity growth in several European countries using new databases that allow us to take into account of intangible assets. We are particularly interested in the European databases that were made using the framework of two European reaserch projects: EUKLEMS and INNODRIVE. The first database, which is largely described and discussed in the first part, pertains to growth accounting and its main contribution is the disaggregation of tangible capital assets and, specifically, it isolates ICT components. The second database, resulting from the INN-ODRIVE project, is more recent and is the first available database that assesses intangible investment according to the methodology of Corrado Hulten and Sichel (2005 [56]) and it consequentially redefines the value-added for European countries.

The first aim of this chapter is to confirm the essential role played not only by the diffusion of information and communication technologies but also by all the innovative activities measured by all R&D investments as well as the investments in organization, in brand equity or in personnel training with all these assets being grouped under the name of intangible investments. The second aim is to reveal specificities for European countries and the third is to study the 2000 break in Europe. For this purpose, we use a new type of growth accounting framework as defined by Corrado Hulten and Sichel

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(2006 [57], called CHS thereafter). In fact, this section, with the exception of small methodological changes, is very close to a study by Jona-Lasinio, Iommi and Manzocchi (2011 [131]) who were members of the working group of the European project INNODRIVE. We carry out a similar study in order to establish specific bases, which we will develop in the next chapter, for the analysis of the relationship that exists between all these assets that, in turn, lead to productivity improvements. In addition, we extend their study by analysing the rupture in productivity following the dotcom crisis.

In the first part, we briefly describe the features of the data sources that we use, as we have already discussed within the previous chapters. The next section outlines the methodology of growth accounting in the outline of CHS and the theoretical impact of the capitalization of intangibles. Finally, the third section presents the results of the labour productivity growth accounting for 11 European countries between 1996 and 2005 and highlights the contribution of the capitalization of intangibles towards labor productivity growth during this period. We also discuss the nature and the potential origins of the differences between countries; in particular, we show that a large share of these differences is due to a "knowledge" factor, rather than to a traditional tangible capital deepening heterogeneity. However, an important part of this knowledge factor is still not understood, despite the fact that accounting for intangibles reduces the weight of this unknown contribution. The other point that we will address in this section is the break in productivity that occurred after the dotcom crisis and the role played by intangible capital deepening in this evolution.

## 7.2 Data description

### 7.2.1 Data sources

To achieve this growth accounting, we used two main data sources: EUKLEMS and INNODRIVE and we checked the data to ensure that it was consistent with that of Eurostat and AMECO.

As described above, EU KLEMS provides data on the macro and sectoral levels for European countries and for the United-States in order to assess growth productivity sources. In particular, it provides details on ICT capital assets and allows us to determine their contribution towards labor productivity growth under a traditional national accounting system. For further details on this database, refer to the detailed description of the data sources and methodology provided by O'Mahony et al. (2009 [176]).

INNODRIVE is a recent database that provides data on intangible capital including details on the three main categories of assets identified by CHS (2005 [56]) and described in the previous section:

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computerized information<sup>1</sup>, innovative properties and economic competencies, and even on subcategories. The assessment of the amount of intangible investment is based on an expenditure approach and follows the assumptions made by CHS (2005 [56]) regarding the proportion of intangible expenditure to be capitalized. This database covers all the 27 European countries and Norway at the macro level for a time period from 1995 to 2005. Nevertheless, the data is not complete for all of these countries. A detailed description of the methodology and the data sources is provided by Piekola (2011 [186]) and by Görzig et al. (2010 [96]).

So, in view of the availability and reliability of the data provided by these sources, our analysis covers 11 EU countries over the period 1996 - 2005 and we limit our approach to the macroeconomic level, and, in particular, this study treats non-agricultural market sectors as a whole sector.

Here is a more detailed breakdown of the distribution of data by its numerous sources:

- Data on value added were extracted from EU KLEMS and AMECO databases (as they are consistent with each other) when used for conventional growth accounting. For the case of augmented growth accounting, including intangibles, the value added were provided by INNODRIVE which adds intangible investments to the national account value-added provided by EU KLEMS.
- Data on hours worked were also taken from both EU KLEMS and AMECO databases (they are also consistent with Eurostat).
- In order to take into account labor qualification as a source of growth, we used EU KLEMS which provides both the share of each labor qualification in hours worked and in labor compensation. However, we do not have data on this subject for Sweden or Portugal
- Concerning data on capital stocks, we used EU KLEMS or INNODRIVE according to the asset:
  - For all tangible assets (non-ICT and ICT tangible capital) and for software capital we used EU KLEMS;
  - For all intangible assets (except for software) data was taken from INNODRIVE.<sup>2</sup>
- Data on deflators and depreciation rates are taken from INNODRIVE for each intangible asset (except software) and from EU KLEMS for all other assets.

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<sup>1</sup>It basically coincides with computer software and INNODRIVE refers to EU KLEMS for this asset

<sup>2</sup>A part of intangible capital is already included in the national accounts, so we deduce the total tangible capital from total capital given by EUKLEMS less this intangible part, given by INNODRIVE.



### 7.2.2 The construction of new input compensation

Since the value added is reassessed, we must recalculate the capital compensation, taking into account intangible investment. In fact, we assume that the entire value added is allocated between the remuneration of labor and capital. However, the capitalization of intangible assets does not affect all the factors' compensation in the same way. On one hand, the total labor compensation is given by national accounts and the reconsideration of intangibles as capital assets does not change the amount of this compensation. On the other hand, the total capital compensation, as well as that of each asset type, should be revalued. Firstly, capital compensation is deduced from the part of value added that is not attributed to labor compensation, which is increased by the amount of intangible investments, and secondly, the relative compensation of a unit of each capital asset (the cost of use of each asset) depends on the no-arbitrage boundary between them and these conditions are changed when we include the intangible assets.

As investments are accounted at year end, we assume that they are used to produce only from the following year. Therefore, we suppose that the productive capital in period  $t$  is actually the capital of period  $t-1$ .

We deduce the total capital compensation as nominal value added ( $VA_t$ ) minus the compensation of labor ( $w_{L,t}L_t$ ):

$$VA_t - w_{L,t}L_t = \sum_j w_{j,t}^K K_{j,t-1} \quad (7.1)$$

where  $K_{j,t}$  is the capital stock of the asset  $j$  at time  $t$ . Furthermore, according to the no-arbitrage boundary, the cost of use of the asset  $j$  (or the price of capital services from the asset type  $j$ ) can be defined as following:

$$w_{j,t}^K = (i_t - g_{j,t}) \times P_{j,t-1}^I + \delta_j \times P_{j,t}^I \quad (7.2)$$

Where  $i_t$  is the nominal rate of return (nominal interest rate) common to all capital assets,  $g_{j,t}$  is the asset specific capital loss that we assumed to be equal to the rate of growth of the investment price,  $g_{j,t} = \frac{P_{j,t}^I - P_{j,t-1}^I}{P_{j,t-1}^I}$ ,  $\delta_j$  is the depreciation rate of the asset  $j$  and  $P_{j,t}^I$  is the investment price at time  $t$ .

We, thus, derived the common nominal rate of return:

$$i_t = \frac{VA_t - w_{L,t}L_t + \sum_j (P_{j,t}^I - P_{j,t-1}^I) K_{j,t-1} - \sum_j \delta_j P_{j,t}^I K_{j,t-1}}{\sum_j P_{j,t-1}^I K_{j,t-1}} \quad (7.3)$$

In this way, we assume that the total value of capital services equals the compensation for all assets, thereby ensuring complete consistency between income and production accounts.

Consequently, if we consider intangibles expenditures as investment, the nominal rate of return should change both because the valuation of the value added is upgraded and because the number of capital assets rises. Thus, the cost of use of a given asset should also change when we introduce intangibles as capital.

### 7.3 Growth accounting taking intangibles into account: Theory

In this chapter, we use the growth accounting methodology pioneered by Solow (1957 [212]) and developed by Jorgenson and Griliches (1967 [132]). The aim of this approach is to decompose output growth into the contribution of inputs and productivity and, in this way, assess the relative importance of each production factor and the multi factor productivity (MFP also called the Solow residual, which is the portion that is not attributed to the inputs). The MFP reflects either the technical progress or measurement errors and unmeasured output or inputs.

We will compare two different sources of growth (SOG) models. The first, qualified as conventional, is the most routinely applied model. In this first approach, we only consider traditional capital assets and the official accounting of the value added. While in the second approach, we consider intangible expenditures as investment and, for that purpose, we use the new accounting of value added as defined by Corrado, Hulten and Sichel (2005 [56] and 2006 [57]). Thus, when the first methodology disregards the impact of accumulation of intangible assets, such as R&D or organizational competencies, on economic growth, on the contrary, the second method allows us to determine whether these assets can explain part of economic growth.

Box 4.3.1 we saw in chapter 4, reminded us of the traditional SOG model and its implementation and we set up our augmented framework on this basis. Our new Cobb Douglas function including intangible capital assets takes the following form:

$$Y = A \prod_l L_l^{\alpha_l} \prod_k K_k^{\alpha_k} \prod_j K_{ICTj}^{\alpha_j} \prod_i K_{Int,i}^{\alpha_i} \quad (7.4)$$

with  $\sum_l \alpha_l + \sum_k \alpha_k + \sum_j \alpha_j + \sum_i \alpha_i = 1$

Where  $Y$  is the value added;  $L_l$  is the quantity of hours worked by labour with a skill level  $l$ ,  $K_k$  is the non ICT tangible capital of type  $k$ ;  $K_{ICTj}$  is the ICT tangible capital of type  $j$ ;  $K_{Int,i}$  is the intangible capital of type  $i$  and  $A$  stands for multifactor productivity.

The coefficients  $\alpha_q$  are defined as the shares of the compensation of the factors  $q$  in the total cost:  $\alpha_q = \frac{w_q X_q}{\sum_q w_q X_q} = \frac{w_q X_q}{P_Y Y}$ . Where  $X_q$  is the quantity of factor  $q$  used.

Then, we can log linearize and differentiate and we obtain:

$$d \ln Y = d \ln A + \sum_l \alpha_l d \ln L_l + \sum_k \alpha_k d \ln K_k + \sum_i \alpha_i d \ln K_{ICT,i} + \sum_i \alpha_i d \ln K_{Int,i} \quad (7.5)$$

Or if we focus on labor productivity:

$$d \ln Y - d \ln L = d \ln A + \sum_l \alpha_l d \ln s_l + \sum_k \alpha_k d \ln \frac{K_k}{L} + \sum_i \alpha_i d \ln \frac{K_{ICT,i}}{L} + \sum_i \alpha_i d \ln \frac{K_{Int,i}}{L} \quad (7.6)$$

The capital deepening contribution of an asset  $n$  is captured by  $\alpha_n d \ln \frac{K_n}{L}$ , the contribution of changes in labor composition by  $\sum_l \alpha_l d \ln s_l$  and the rate of growth of the total factor productivity is captured by  $d \ln A$ . And in practice these contributions are approximated by:

$$\frac{1}{2} (\alpha_{q,t} + \alpha_{q,t-1}) \ln \left( \frac{X_{q,t}}{X_{q,t-1}} \right) \quad (7.7)$$

In order to proceed with the comparison between these two growth accounting methods, it is necessary to grasp the theoretical impact of the change in methodology. Box 6.5.2 in the previous chapter describes the theoretical consequences of the inclusion of intangible assets. In particular, we recall that the two consequences of this accounting extension is:

1. The GDP growth rate is modified if the growth rate of intangible investment is different from the growth rate of GDP measured by the national accounts;
2. The contribution of labor and tangible capital are reduced by a factor of proportionality.

## **7.4 Results and analysis: the European heterogeneity**

### **7.4.1 Over the whole period: intangibles differ deeply between countries**

In order to analyse our results on hourly labor productivity sources, we first focus on the entire period 1996-2005. Table 7.1 provides the results of the two growth accounting models (the conventional one and the one with capitalization of intangibles) over this period for the non-agricultural market sectors in our eleven studied countries. Table 7.2 summarizes the impact of the capitalization of intangibles on growth accounting. It sums up the aggregated contributions to labor productivity growth in order to compare the two sources of growth models as follows. In both growth accounting, with or without intangibles, the National Account Capital Deepening (NACD) represents the capital deepening of capital assets that were already included in the traditional growth accounting. It includes all tangible assets but also a part of intangible assets and especially Computerized information, Mineral exploration, Copyright and license costs. Thus, the NACD matches the contributions of exactly the same assets as those included in the total capital deepening in conventional growth accounting. In contrast, the New Intangible Capital Deepening (NICD) represents the capital deepening of intangible assets that are not capitalized in conventional national accounts. It includes the remaining intangible assets. In this table, the multifactor productivity contribution includes the contribution of changes in labor composition.

First of all, focusing on the annual average growth of labor productivity in conventional growth accounting (at the top of table 7.1), we observe a strong heterogeneity between countries in Europe. Indeed, in the two Nordic countries, Sweden and Finland, that are the most performant countries during this period, labor productivity grows, on average, respectively at 3,46% and 2,74% per year, whereas, in the two Mediterranean countries, Italy and Spain, labor productivity growth is, on average, only 0,15% and 0,27% respectively. In addition, the standard deviation of average labor productivity growth over this period is about 1 point (table 7.2), which is, in proportion, relatively high. In this way, we see that the apparent European gap with respect to the U.S. cannot be considered as generalised and homogenous in Europe since, in some countries labor productivity grows at the same rate or even faster than that in the US (2.75% per year over this period according to Van Ark et al., 2009 [225]) while in some other countries labor productivity is almost stagnant. The understanding of the European productivity growth lag is thus conditioned by the understanding of European heterogeneity. Furthermore, observation of the upper table 7.1 reveals that the MFP in conventional growth accounting, that is to say the unexplained growth, plays a major role and thus, even

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Table 7.1: Sources of productivity growth for the period 1996-2005\*

	AT	DK	FI	FR	DE	IT	NL	PT	ES	SE	UK
<b>Conventional Growth Accounting*</b>											
Labour Productivity Growth	1,87%	1,02%	2,74%	2,11%	1,82%	0,15%	2,20%	1,52%	0,27%	3,46%	2,19%
MFP	0,59%	-0,06%	2,17%	1,20%	0,59%	-0,50%	0,88%	-0,82%	-0,44%	2,21%	0,46%
Labour Composition	0,19%	0,19%	0,07%	0,37%	0,00%	0,12%	0,21%		0,45%		0,49%
Non ICT tangible capital	0,64%	0,13%	0,15%	0,26%	0,89%	0,30%	0,60%	1,64%	-0,01%	0,77%	0,50%
ICT capital	0,46%	0,77%	0,35%	0,29%	0,33%	0,23%	0,51%	0,70%	0,27%	0,48%	0,73%
Computing Equipment	0,29%	0,47%	0,08%	0,09%	0,22%	0,16%	0,31%	0,43%	0,14%	0,22%	0,44%
Communication Equipment	0,04%	0,01%	0,20%	0,04%	0,03%	0,03%	0,03%	0,14%	0,07%	0,12%	0,12%
Software	0,13%	0,29%	0,08%	0,16%	0,08%	0,04%	0,16%	0,13%	0,06%	0,14%	0,17%
<b>Growth Accounting with Intangibles*</b>											
Labour Productivity Growth	2,04%	1,10%	2,80%	2,15%	1,89%	0,22%	2,23%	1,65%	0,30%	3,43%	2,30%
MFP	0,52%	-0,09%	1,98%	1,11%	0,50%	-0,47%	0,71%	-0,80%	-0,40%	1,87%	0,41%
Labour Composition	0,18%	0,17%	0,06%	0,34%	0,00%	0,11%	0,20%		0,43%		0,45%
Non ICT tangible capital	0,59%	0,12%	0,14%	0,23%	0,81%	0,28%	0,55%	1,54%	-0,01%	0,67%	0,46%
ICT capital	0,30%	0,44%	0,26%	0,12%	0,23%	0,19%	0,32%	0,54%	0,20%	0,30%	0,51%
Computing Equipment	0,27%	0,43%	0,07%	0,09%	0,20%	0,16%	0,29%	0,41%	0,14%	0,19%	0,40%
Communication Equipment	0,03%	0,01%	0,18%	0,03%	0,03%	0,03%	0,03%	0,13%	0,07%	0,11%	0,11%
Intangible capital	0,45%	0,46%	0,37%	0,35%	0,34%	0,11%	0,46%	0,37%	0,07%	0,58%	0,46%
Computerized information	0,12%	0,27%	0,07%	0,14%	0,08%	0,03%	0,15%	0,13%	0,06%	0,13%	0,15%
Software	0,12%	0,27%	0,07%	0,14%	0,08%	0,03%	0,15%	0,13%	0,06%	0,13%	0,15%
Database											
Innovative Properties	0,19%	0,15%	0,23%	0,10%	0,16%	0,04%	0,13%	0,11%	0,02%	0,28%	0,10%
Scientific R&D	0,11%	0,10%	0,20%	0,03%	0,06%	-0,01%	0,03%	0,02%	0,01%	0,19%	0,01%
Non Scientific R&D	0,08%	0,05%	0,04%	0,07%	0,09%	0,05%	0,10%	0,08%	0,01%	0,09%	0,09%
Mineral exploration	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,01%	0,00%	0,01%	-0,01%
Copyright and license costs											
New prod. devpt. cost in fin. indus.	0,03%	0,01%	-0,01%	0,01%	0,04%	0,03%	0,05%	0,05%	-0,01%	0,00%	0,04%
New arch. and eng. designs	0,05%	0,04%	0,05%	0,05%	0,04%	0,02%	0,05%	0,02%	0,01%	0,08%	0,06%
Economic Competencies	0,13%	0,03%	0,07%	0,11%	0,11%	0,04%	0,17%	0,14%	-0,01%	0,18%	0,21%
Brand Equity	0,06%	0,02%	0,03%	0,02%	0,02%	0,03%	0,04%	0,06%	0,00%	0,03%	0,04%
Advertising expenditure	0,05%	0,00%	0,02%	0,01%	0,01%	0,02%	0,01%	0,03%	0,00%	0,02%	0,02%
Market research	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,04%	0,02%	0,00%	0,01%	0,02%
Firm specific resources	0,07%	0,02%	0,04%	0,09%	0,09%	0,01%	0,13%	0,08%	-0,01%	0,15%	0,17%
Firm-specific human capital	0,01%	0,00%	-0,02%	0,02%	0,01%	-0,01%	0,00%	0,00%	-0,01%	0,02%	0,02%
Purchased org. structures	0,05%	0,01%	0,02%	0,05%	0,06%	0,02%	0,10%	0,06%	0,00%	0,11%	0,09%
Own account devpt of org. struct.	0,02%	0,01%	0,04%	0,03%	0,01%	0,00%	0,03%	0,02%	0,00%	0,02%	0,06%

\*For non agricultural market sectors (C to K + O)

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Table 7.2: Impact of intangibles as capital on growth accounting

	Conv. G.A.			G.A. with Intangibles				Differences		
	LPG (1)	NACD (2)	MFPG (3)	LPG (4)	NACD (5)	NICD (6)	MFPG (7)	LPG (4-1)	CD (5+6-2)	MFPG (7-3)
Austria	1,87	1,09	0,78	2,04	1,02	0,32	0,70	0,16	0,25	-0,08
Denmark	1,02	0,90	0,12	1,10	0,84	0,18	0,08	0,08	0,12	-0,04
Finland	2,74	0,50	2,24	2,80	0,46	0,30	2,04	0,06	0,27	-0,20
France	2,11	0,54	1,57	2,15	0,50	0,20	1,45	0,04	0,16	-0,12
Germany	1,82	1,22	0,60	1,89	1,13	0,25	0,51	0,07	0,16	-0,09
Italy	0,15	0,53	-0,38	0,22	0,51	0,08	-0,36	0,08	0,05	0,02
Netherlands	2,20	1,11	1,09	2,23	1,02	0,30	0,91	0,03	0,22	-0,19
Portugal	1,52	2,34	-0,82	1,65	2,22	0,23	-0,80	0,12	0,11	0,01
Spain	0,27	0,26	0,01	0,30	0,25	0,01	0,03	0,03	0,00	0,02
Sweden	3,46	1,24	2,21	3,43	1,10	0,45	1,87	-0,03	0,31	-0,34
United Kingdom	2,19	1,23	0,96	2,30	1,11	0,32	0,86	0,11	0,20	-0,09
Std. Dev.	0,99	0,57	0,99	0,98	0,53	0,12	0,90	-0,01	0,03*	-0,10

\*Std. Dev.(5+6) - Std. Dev.(2)

LPG: Labor Productivity Growth;

NACD: National Account Capital Deepening;

NICD: New Intangible Capital Deepening;

MFPG: Multi-Factor Productivity growth (including labor composition).

if ICT capital deepening contributes to explaining these inequalities, thus, this is far from sufficient.

Now, the comparison of the two growth accounting models, including intangibles or not (the comparison between the higher and the lower part of table 7.1), firstly, shows that considering intangibles as capital tends to increase labor productivity growth (except in Sweden). This means that investments in intangibles are growing faster than the conventional value added in these European countries. Nevertheless, the capitalization of intangibles does not globally change the ranking of countries in terms of annual labor productivity growth. Moreover, the bottom of table 7.2 also shows that the standard deviation of the hourly labor productivity growth between countries is almost the same in both growth accounting models which implies that capitalization has no impact on the divergence between the European countries.

Secondly, we see that the contributions of inputs already used in traditional accounting mechanically decrease as demonstrated in Corrado, Hulten and Sichel (2006 and 2009 [57, 58]) (see box 6.5.2).

Thirdly, multifactor productivity growth is still important and is the first factor of labor productivity growth in three countries (Finland, France and the Netherlands) and also seems to be strong in Sweden where the sum of MFP and labor composition contributes about 1.87% to annual growth.

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But by expanding the definition of capital to intangible assets, the contribution of the MFP is reduced (in absolute value) and in this way, considering intangibles as capital seems, thus, to better explain productivity growth.

Furthermore, it significantly reduces the standard deviation in the MFP between countries<sup>3</sup> (of 10%, according to the bottom of the table 7.2) and consequently the capitalization of intangibles also seems to improve the explanation for the productivity divergence in the European countries.

We remark in table 7.1 that four countries show a negative contribution of MFP (Denmark, Italy, Portugal and Spain), which implies that in these countries, MFP is decreasing and, with the exception of Denmark, the introduction of intangibles slightly reduces this negative impact (or at least it remains relatively stable). This observation is always true when MFP includes the changes in labor composition that may be unevenly measured across countries.

In addition, the following observations can be made. As pointed out by Jona-Lasinio et al. (2011 [131]), three of the four countries with the highest labor productivity growth, which are Sweden, United Kingdom<sup>4</sup> and Netherlands, are the three with the highest intangible contribution. And conversely, the two countries with the lowest labor productivity growth, which are Italy and Spain, are also the two with the lowest intangible contribution. Moreover, these countries also show a low MFP growth rate. Finally, over the period 1996-2005, the ranking of LPG (Labor Productivity Growth) is almost the same as the ranking of the contribution of knowledge economy<sup>5</sup> according to figure 7.1. Note that the ranking of the contribution of knowledge economy does not match the LPG ranking only in France and Portugal.

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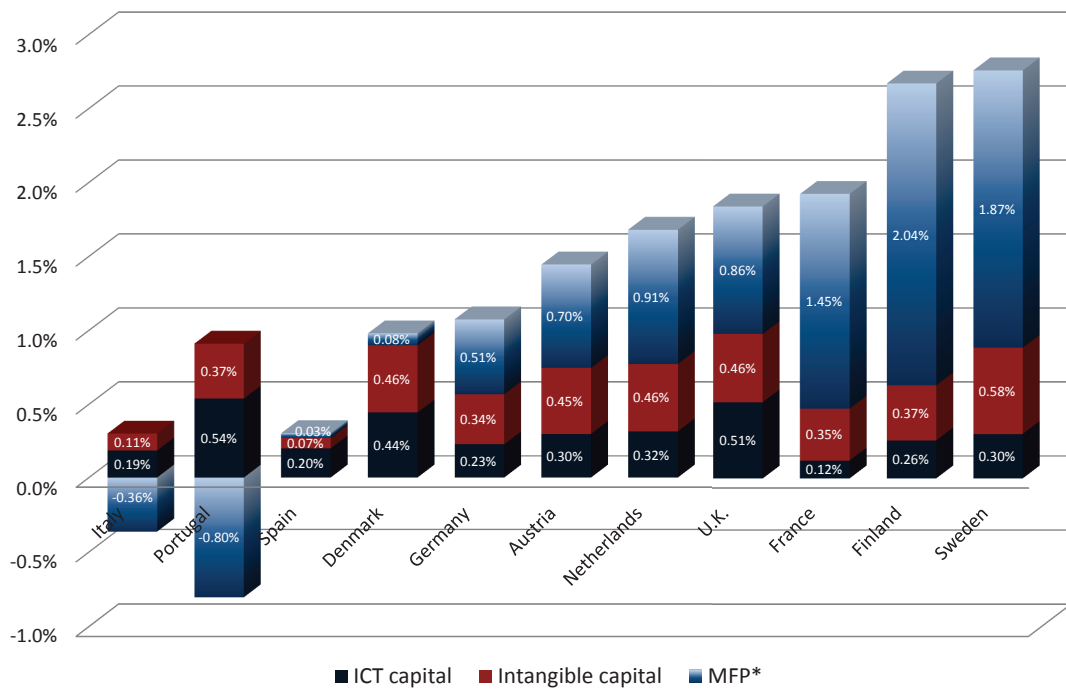
<sup>3</sup>We group together MFP and labor composition in order to compare all countries

<sup>4</sup>The United-Kingdom is the country where the contributions are the most balanced.

<sup>5</sup>Including ICT and intangible capital deepening, labor composition and MFP

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Figure 7.1: Contribution of “*Knowledge Economy*” to labor productivity growth over the 1996-2005 period



\*MFP includes labor composition here



### 7.4.2 The 2000's break

This part provides one the contribution of this chapter and deals with the productivity slowdown during the post dot-com crisis period. For this, we split the period into two parts: 1996-2000 and 2000-2005.

Tables 7.3 and 7.4 show the evolution of average hourly labor productivity growth and the respective contribution of factors between these two periods 1996-2000 and 2000-2005. Our intent is to highlight the impact of the dotcom crisis on productivity growth in each source of growth model.

If we focus on conventional SOG, labor productivity growth slows down in almost all countries in our sample between these two periods 1996-2000 and 2000-2005 (except in Denmark and Spain, and Sweden) and this slowdown is relatively important since it is often around, or exceeds, one percentage point. Consequently, we do not observe the same trend as in the US where productivity continues its growth or even accelerates (from 2.70% during 1995-2000 to 3.09% per year during 200-2005) as highlighted by Jorgenson, Ho and Stiroh (2008 [136]).

These two periods frame<sup>6</sup> the year 2000 dot-com crisis and, in this regard, as expected, the contribution of ICT diminishes strongly after 2000 except in Portugal and Spain. However, we note that, surprisingly, the different components of ICT (Computing equipment, Communication equipment and software) are not homogeneously affected, neither over time nor in the same way in all countries. For instance, on one hand, in Finland, IT capital deepening strongly decreases whereas Software increases and CT remains relatively constant and, on the other hand, software capital deepening increases in Austria, Finland, Portugal, Spain but decreases in Denmark, France, Italy, the Netherlands and United-Kingdom and remains relatively stable in the other countries.

Table 7.4 highlights the fact that capitalization of intangible assets plays negatively on the labor productivity growth variations in all countries except in France where the impact seems to be insignificant. Especially as it increases the weight of the negative variation of MFP growth in 2000.

Acknowledging that we qualify MFP as the measure of our ignorance, it is thus, a priori, paradoxical to argue that, on one hand, the capitalization of intangibles better explains productivity growth by decreasing the weight of MFP contributions while, conversely on the other hand, it seems to blur the origins of productivity acceleration or deceleration by increasing the weight of MFP growth variations. However, this observation reflects the fact that intangible investments, accounted for in output and in

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<sup>6</sup>The dot-com bubble reached its climax on March 10<sup>th</sup>, 2000

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Table 7.3: Growth accounting for the periods 1996-2000 and 2000-2005

	AT		DK		FI		FR		DE	
	96-00	00-05	96-00	00-05	96-00	00-05	96-00	00-05	96-00	00-05
<b>Conventional Growth Accounting*</b>										
Labour Productivity Growth	2,73%	1,19%	0,61%	1,35%	3,10%	2,45%	2,88%	1,50%	1,98%	1,68%
MFP	1,38%	0,01%	-0,11%	0,00%	3,15%	1,31%	2,01%	0,58%	0,94%	0,33%
Labour Composition	0,24%	0,12%	0,21%	0,15%	0,01%	0,14%	0,51%	0,25%	-0,07%	0,06%
Non ICT tangible capital	0,62%	0,65%	-0,45%	0,59%	-0,47%	0,66%	0,04%	0,42%	0,77%	0,98%
ICT capital	0,48%	0,41%	0,96%	0,60%	0,41%	0,35%	0,32%	0,24%	0,34%	0,31%
Computing Equipment	0,34%	0,24%	0,61%	0,36%	0,19%	0,02%	0,11%	0,08%	0,24%	0,19%
Communication Equipment	0,04%	0,03%	0,00%	0,02%	0,19%	0,21%	0,04%	0,04%	0,03%	0,03%
Software	0,11%	0,14%	0,35%	0,22%	0,03%	0,11%	0,18%	0,12%	0,07%	0,09%
<b>Growth Accounting with Intangibles*</b>										
Labour Productivity Growth	3,01%	1,27%	0,75%	1,38%	3,29%	2,42%	2,92%	1,54%	2,26%	1,59%
MFP	1,40%	-0,13%	-0,06%	-0,11%	3,05%	1,03%	1,93%	0,48%	1,09%	0,05%
Labour Composition	0,23%	0,12%	0,20%	0,14%	0,01%	0,13%	0,47%	0,23%	-0,06%	0,05%
Non ICT tangible capital	0,58%	0,61%	-0,42%	0,56%	-0,43%	0,62%	0,04%	0,39%	0,71%	0,89%
ICT capital	0,35%	0,25%	0,56%	0,35%	0,35%	0,22%	0,13%	0,11%	0,25%	0,21%
Computing Equipment	0,32%	0,22%	0,56%	0,33%	0,17%	0,02%	0,10%	0,08%	0,23%	0,18%
Communication Equipment	0,04%	0,03%	0,00%	0,02%	0,18%	0,20%	0,04%	0,03%	0,02%	0,03%
Intangible capital	0,45%	0,42%	0,47%	0,43%	0,31%	0,43%	0,35%	0,33%	0,28%	0,39%
Computerized information	0,10%	0,13%	0,32%	0,21%	0,03%	0,10%	0,16%	0,11%	0,07%	0,08%
Software	0,10%	0,13%	0,32%	0,21%	0,03%	0,10%	0,16%	0,11%	0,07%	0,08%
Database										
Innovative Properties	0,18%	0,20%	0,09%	0,20%	0,19%	0,27%	0,05%	0,14%	0,11%	0,19%
Scientific R&D	0,10%	0,12%	0,07%	0,12%	0,19%	0,20%	0,02%	0,03%	0,03%	0,09%
Non Scientific R&D	0,08%	0,08%	0,02%	0,08%	0,00%	0,06%	0,03%	0,11%	0,08%	0,10%
Mineral exploration	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	0,01%	0,01%	0,01%
Copyright and license costs										
New prod. devpt. cost in fin. indus.	0,03%	0,03%	0,00%	0,02%	-0,03%	0,00%	0,00%	0,02%	0,03%	0,05%
New arch. and eng. designs	0,05%	0,05%	0,02%	0,06%	0,03%	0,06%	0,03%	0,08%	0,04%	0,04%
Economic Competencies	0,18%	0,09%	0,06%	0,02%	0,10%	0,06%	0,14%	0,09%	0,10%	0,11%
Brand Equity	0,10%	0,02%	0,02%	0,02%	0,06%	0,01%	0,03%	0,01%	0,04%	0,00%
Advertising expenditure	0,08%	0,02%	0,02%	-0,01%	0,04%	0,00%	0,03%	-0,01%	0,03%	-0,01%
Market research	0,02%	0,00%	0,00%	0,02%	0,02%	0,01%	0,00%	0,02%	0,01%	0,02%
Firm specific resources	0,08%	0,07%	0,04%	0,00%	0,04%	0,05%	0,11%	0,08%	0,06%	0,11%
Firm-specific human capital	0,01%	0,01%	0,01%	-0,02%	0,00%	-0,03%	0,01%	0,02%	0,01%	0,01%
Purchased org. structures	0,04%	0,05%	0,01%	0,01%	0,02%	0,02%	0,09%	0,01%	0,06%	0,07%
Own account devpt of org. struct.	0,03%	0,01%	0,01%	0,01%	0,02%	0,05%	0,01%	0,04%	0,00%	0,02%

\*For non agricultural market sectors (C to K + O)

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	IT		NL		PT		ES		SE		UK	
	96-00	00-05	96-00	00-05	96-00	00-05	96-00	00-05	96-00	00-05	96-00	00-05
<b>Conventional Growth Accounting*</b>												
Labour Productivity Growth	0,96%	-0,50%	2,45%	2,01%	2,60%	0,67%	-0,09%	0,56%	3,33%	3,56%	2,50%	1,94%
MFP	0,38%	-1,19%	1,54%	0,31%	0,51%	-1,85%	-0,28%	-0,62%	2,29%	2,18%	0,56%	0,42%
Labour Composition	0,08%	0,14%	0,10%	0,34%			0,48%	0,42%			0,63%	0,36%
Non ICT tangible capital	0,18%	0,39%	0,16%	0,97%	1,44%	1,79%	-0,61%	0,50%	0,46%	0,99%	0,41%	0,56%
ICT capital	0,32%	0,16%	0,65%	0,39%	0,66%	0,73%	0,31%	0,26%	0,58%	0,39%	0,90%	0,60%
Computing Equipment	0,21%	0,13%	0,45%	0,22%	0,48%	0,38%	0,22%	0,09%	0,30%	0,15%	0,56%	0,37%
Communication Equipment	0,06%	0,01%	0,03%	0,03%	0,12%	0,15%	0,05%	0,09%	0,15%	0,10%	0,15%	0,10%
Software	0,05%	0,02%	0,17%	0,14%	0,06%	0,21%	0,04%	0,08%	0,13%	0,14%	0,20%	0,13%
<b>Growth Accounting with Intangibles*</b>												
Labour Productivity Growth	1,23%	-0,57%	2,76%	1,81%	2,76%	0,77%	-0,05%	0,57%	3,61%	3,28%	2,81%	1,88%
MFP	0,54%	-1,27%	1,61%	-0,06%	0,55%	-1,88%	-0,22%	-0,59%	2,22%	1,61%	0,67%	0,24%
Labour Composition	0,08%	0,13%	0,09%	0,31%			0,46%	0,40%			0,57%	0,32%
Non ICT tangible capital	0,17%	0,38%	0,14%	0,90%	1,33%	1,71%	-0,58%	0,49%	0,40%	0,87%	0,37%	0,52%
ICT capital	0,25%	0,13%	0,44%	0,23%	0,56%	0,50%	0,26%	0,17%	0,40%	0,22%	0,64%	0,43%
Computing Equipment	0,20%	0,12%	0,41%	0,20%	0,45%	0,36%	0,21%	0,09%	0,27%	0,13%	0,50%	0,34%
Communication Equipment	0,06%	0,01%	0,03%	0,03%	0,11%	0,14%	0,05%	0,08%	0,13%	0,09%	0,13%	0,09%
Intangible capital	0,18%	0,06%	0,48%	0,43%	0,31%	0,44%	0,03%	0,11%	0,59%	0,58%	0,57%	0,37%
Computerized information	0,05%	0,02%	0,16%	0,13%	0,06%	0,20%	0,04%	0,08%	0,12%	0,13%	0,18%	0,12%
Software	0,05%	0,02%	0,16%	0,13%	0,06%	0,20%	0,04%	0,08%	0,12%	0,13%	0,18%	0,12%
Database												
Innovative Properties	0,05%	0,04%	0,12%	0,15%	0,12%	0,10%	-0,02%	0,05%	0,25%	0,30%	0,12%	0,08%
Scientific R&D	-0,02%	0,00%	0,02%	0,03%	0,01%	0,03%	0,00%	0,02%	0,17%	0,21%	0,00%	0,01%
Non Scientific R&D	0,06%	0,04%	0,10%	0,11%	0,11%	0,07%	-0,01%	0,03%	0,08%	0,10%	0,12%	0,07%
Mineral exploration	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,00%	0,01%	0,01%	0,01%	-0,01%	-0,01%
Copyright and license costs												
New prod. devpt. cost in fin. indus.	0,03%	0,02%	0,04%	0,05%	0,06%	0,05%	-0,01%	0,00%	0,00%	0,01%	0,06%	0,02%
New arch. and eng. designs	0,03%	0,01%	0,05%	0,05%	0,04%	0,00%	0,00%	0,02%	0,07%	0,08%	0,08%	0,05%
Economic Competencies	0,09%	0,00%	0,21%	0,16%	0,14%	0,14%	0,01%	-0,02%	0,22%	0,15%	0,26%	0,16%
Brand Equity	0,07%	0,00%	0,09%	0,01%	0,10%	0,04%	0,02%	-0,02%	0,06%	0,01%	0,06%	0,02%
Advertising expenditure	0,03%	0,00%	0,04%	-0,01%	0,09%	-0,01%	0,02%	-0,01%	0,04%	0,00%	0,05%	0,01%
Market research	0,03%	0,00%	0,05%	0,03%	0,00%	0,04%	0,00%	-0,01%	0,01%	0,01%	0,02%	0,02%
Firm specific resources	0,02%	0,00%	0,12%	0,14%	0,04%	0,10%	-0,01%	0,00%	0,16%	0,14%	0,20%	0,14%
Firm-specific human capital	-0,01%	-0,02%	0,02%	-0,01%	0,01%	0,00%	-0,01%	-0,01%	0,02%	0,01%	0,02%	0,02%
Purchased org. structures	0,04%	0,01%	0,08%	0,11%	0,04%	0,06%	0,00%	0,01%	0,13%	0,09%	0,12%	0,07%
Own account devpt. of org. struct.	-0,01%	0,01%	0,01%	0,04%	-0,01%	0,04%	0,00%	0,00%	0,01%	0,03%	0,07%	0,05%

\*For non agricultural market sectors (C to K + O)

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Table 7.4: Impact of intangibles as capital on the 2000's break

	Conv. G.A.			G.A. with Intangibles				Diff.		
	$\Delta$ LPG	$\Delta$ CD	$\Delta$ MFP	$\Delta$ LPG	$\Delta$ NACD	$\Delta$ NICP	$\Delta$ MFP	$\Delta$ LPG	$\Delta$ CD	$\Delta$ MFP
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(4-1)	(5+6-2)	(7-3)
Austria	-1,54	-0,04	-1,49	-1,74	-0,05	-0,06	-1,63	-0,20	-0,06	-0,14
Denmark	0,74	0,69	0,05	0,63	0,65	0,08	-0,10	-0,11	0,04	-0,15
Finland	-0,65	1,07	-1,71	-0,88	0,99	0,04	-1,90	-0,23	-0,04	-0,19
France	-1,38	0,30	-1,68	-1,38	0,27	0,04	-1,69	0,00	0,01	-0,01
Germany	-0,30	0,19	-0,49	-0,68	0,17	0,08	-0,93	-0,38	0,06	-0,44
Italy	-1,46	0,06	-1,52	-1,80	0,06	-0,09	-1,76	-0,34	-0,09	-0,25
Netherlands	-0,45	0,55	-1,00	-0,95	0,53	-0,03	-1,45	-0,50	-0,05	-0,46
Portugal	-1,94	0,43	-2,36	-1,99	0,46	-0,01	-2,43	-0,05	0,02	-0,07
Spain	0,66	1,06	-0,40	0,62	1,02	0,03	-0,42	-0,04	-0,01	-0,03
Sweden	0,23	0,33	-0,11	-0,33	0,30	-0,02	-0,61	-0,56	-0,05	-0,50
United Kingdom	-0,57	-0,15	-0,41	-0,93	-0,11	-0,14	-0,67	-0,36	-0,10	-0,26

capital accumulation, fell after the dotcom crisis and the extent of this fall is greater on the output side (the production of intangible investment goods) than on the input side (intangible capital as a production factor) since in the latter case, the intangible investment is multiplied by the factor's income share ( $\frac{\Delta I_{Int}}{VA} > \alpha_{Int} \frac{\Delta K_{Int}}{K_{Int}}$ ) and, moreover, this variation represents a weaker part of the intangible capital rather than of the value added. This is confirmed by the fact that intangible capital deepening does not fluctuate a lot in Europe.

Among the intangibles, the contributions of the different assets are heterogeneous but, in most countries, every new intangible capital deepening change is in the same direction. Only computerized information capital deepening differs between countries. Innovative property capital deepening increases in almost all countries (except in the U.K.) and, conversely, economic competency capital deepening decreases in all the countries in the post-2000 period.

Furthermore, the simultaneity between the fall in ICT and in intangible investments highlights probably complementarity features between these two assets and thus the fall in MFP contribution between the two periods could also reflect a slowdown in complementary innovation or a complementarity between factors that is included in MFP as long as the growth accounting approach employed assumes that the factors are substitutable.

We remark that Sweden is the country where the inclusion of intangibles has the greatest impact on the year 2000 drop. Indeed, according to conventional growth accounting, Sweden is, alongside

## CHAPTER 7. WHAT SPECIFICITIES FOR EUROPEAN COUNTRIES?

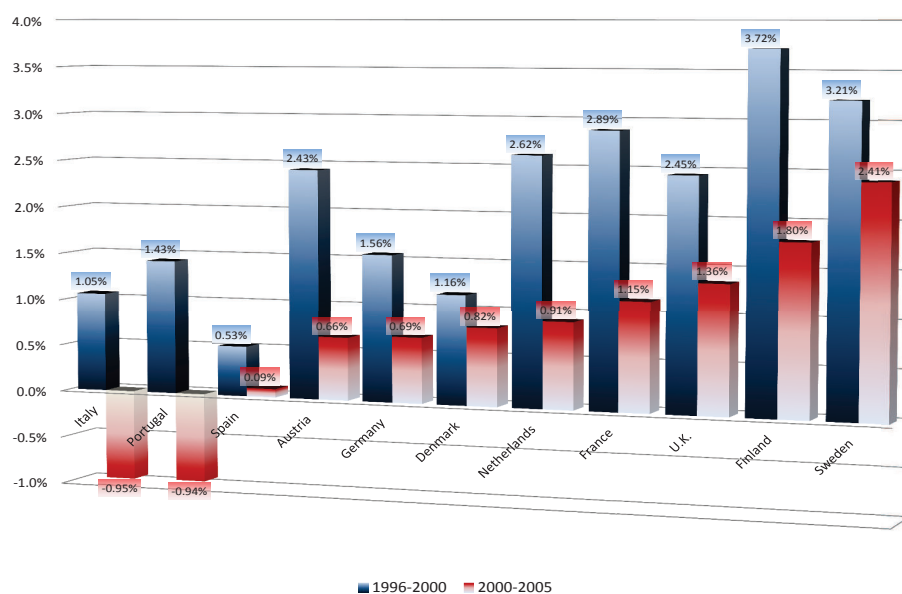
Denmark and Spain, one of the three countries that show a slight acceleration of labor productivity growth after 2000 (0.23 %points), mainly due to capital deepening. But it is no longer the case with the inclusion of intangibles since, on the contrary, according to this new evaluation, labour productivity slows down by 0.33 % points because of a strong fall of the MFP of 0.61% points and the total negative impact of the capitalization of intangible expenditure on the LPG variation is 0.56 % points.

Then finally, between these two periods, multifactor productivity growth declines in all countries and is almost always the first cause of any LPG slowdown.

Acknowledging the fact that, in the United States, labor productivity pursues its growth after the dot-com crisis according to conventional growth accounting, the results obtained by Oliner et al. (2008 [174]) for the US are similar since they found that this labor productivity acceleration is inhibited by the introduction of intangibles as capital. Thus, the capital deepening of the new intangible assets affects the change in year 2000 in the same direction (negatively) in the United States as in the European countries.

These results again show that European productivity is more or less fragile depending on the country and the more fragile economies appear to be those where the economy is the less knowledge-based.

Figure 7.2: Evolution of Contribution of “*Knowledge Economy*” between 1996-2005 and 2000-2005



## 7.5 Concluding Remarks

This chapter opened up with a new growth accounting method pioneered by Corrado, Hulten and Sichel (2006 [57]) taking intangible expenditures into account as investments. In this way, we identify the accumulation of intangible assets as a source of economic growth. As we saw in the previous chapter, considering intangibles as capital helps shed light on the second productivity paradox in the U.S. and in the present chapter we show that it also helps to explain the European productivity growth gap. The results we obtained here are consistent with those obtained by other studies that cover the same countries. We are very close to the results of Jona-Lasinio, Iommi and Manzocchi (2001) since we use the same databases, but we are also consistent with respect to those of Hao, Manole and Van Ark (2008 [113]) or Van Ark, Hao, Corrado and Hulten (2009 [225]).

We show, in this chapter, that European productivity performances are really heterogeneous among countries. Especially, the second half of the period 1996-2005 reveals the solidity of knowledge based economies whereas symptoms of the “Olive Belt” disease appear to worsen after the dot-com crisis. These results suggest, thus, that European economic performance is more likely to strengthen in laggard economies through the improvement of their knowledge production structure. We also note that the capitalization of intangible investments increases their procyclicality mechanically with respect to GDP growth. Consequently, depending on whether they are procyclical or counter-cyclical with respect to GDP measured by national accounts, they should respectively tend to amplify or compress the measured amplitude of economic fluctuations.

Nevertheless, there is still room for improvement in explaining productivity growth. Indeed, setting aside any questionable assumptions inherent to such exercises, whatever the growth accounting method (capitalizing or not intangibles), it does not take into account potential complementarities between factors. Thus, if such complementarities exist, we probably misjudge the contribution of some factors as well as any residual MFP variations. For that matter, the GPT features of the ICT suggest that they could be complementary with intangible assets. The next chapter therefore aims to assess these potential complementarities.



## Chapter 8

# Empirical evidence on strategic complementarity

### 8.1 Introduction

In chapter 6, we discussed the mechanisms that portray a GPT as an engine of growth. In particular, we showed the central role of the innovation complementarities that should exist between ICT-using and -producing industries. The assumption we made in the previous chapter of a Cobb-Douglas production function completely neglects this aspect; therefore, we try to highlight this inadequacy in this chapter. With this aim, we use a new specification allowing us to assess the vertical complementarities between innovation by ICT user and producer. In other words, we seek to provide empirical evidence that innovation by ICT producers generates innovation incentives for ICT users and, reciprocally, this innovation by ICT users encourages ICT producers to innovate in return.

In the two first sections we describe the theoretical model that we use and the econometric specifications, in the third one, we present our estimation results and, before concluding, we show how these results reveal vertical innovation complementarities.

### 8.2 Theoretical model

We base our approach on a two-sector model. The first sector produces an “intermediate knowledge” good, using factors that we define as “knowledge factors” which are especially ICT and intangible



## CHAPTER 8. EMPIRICAL EVIDENCE ON STRATEGIC COMPLEMENTARITY

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capital. The second sector produces the final good, using this intermediate knowledge factor, labor and non-ICT tangible capital.

So, concerning this last sector, we assume that the aggregate production of the final good could be modeled as a Cobb-Douglas function using the three types of factors as follows:

$$Y = AF^\gamma L^\alpha K^\beta \quad (8.1)$$

Where  $L$  is labor<sup>1</sup>,  $K$  is tangible non-ICT capital<sup>2</sup> and  $F$  being the intermediate knowledge factor and  $\gamma + \alpha + \beta = 1$ . In this way, the production function is homothetically separable with respect to its factors  $F$ ,  $L$  and  $K$  and has a Hicks neutral constant exponential technical change.

The “knowledge sector” should be understood in a broad sense; it is supposed to represent the output of all activities that aim to increase productivity either through innovation in the strict sense or through the improvement of the production organization. We assume that the extent of these activities can be assessed by the investments in intangible and ICT assets. And thus this sector uses four categories of factors which are ICT capital, Computing Information (CI) capital, Economic Competencies (EC) capital and Innovative Properties (IP) capital. Moreover, we assume that these factors are only used in these sectors. Thus, the “knowledge sector” combines ICT capital and intangible capital through a positive, twice differentiable strictly quasi-concave production function as follows, without any assumption on the factors’ substitutabilities:

$$F = f(K_{ICT}; K_{CI}; K_{EC}; K_{IP}) \quad (8.2)$$

Hence,  $F$  represents a consistent index of the knowledge inputs or the utilized knowledge capital services. The idea underlying this assumption of a separable knowledge capital services sub-function is that the relative use of each knowledge factor (ICT and intangible capital) depends only on its price  $P_{ICT}$ ,  $P_{CI}$ ,  $P_{EC}$ ,  $P_{IP}$  and not on the prices of the other inputs ( $P_L$  or  $P_K$ )

Furthermore, the hypothesis of perfect competition in this sector leads us to level the price of the

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<sup>1</sup>Because of the lack of data for some countries, we do not take into account the labor composition.

<sup>2</sup>As in the previous section, for the sake of clarity,  $K$  is written here as an aggregate but in our calculus we distinguish five types of non-ICT tangible capital: transport equipment, other machinery equipment, residential structures, other construction and other.

factor F with its unit cost:

$$Cu_F \times F = w_{ICT} \times K_{ICT} + w_{CI} \times K_{CI} + w_{EC} \times K_{EC} + w_{IP} \times K_{IP} = (1 - \alpha - \beta) \times Y \times P_Y \quad (8.3)$$

Where  $\alpha$ ,  $\beta$  and  $1 - \alpha - \beta$  represent the cost shares respectively of the factors L, K and F.

In a similar manner by Berndt and Wood (1979 [19]) in the case of energy-capital complementarity, regarding the sub-inputs, ICT and intangible capital, here we have three types of price elasticities. A first category focuses on price elasticities between these sub-inputs within the same input subset F, holding this aggregate input constant. These elasticities are called the *gross price elasticities* and are defined as follows (where  $X_i$  is the quantity of the sub-input  $i$  and  $P_j$  the price of the sub-input  $j$ ):

$$\epsilon_{ij}^* = \left. \frac{\partial \ln X_i}{\partial \ln P_j} \right|_{F=F_0} \quad (8.4)$$

Whereas a second category defines the price elasticities between the sub-inputs when the final output Y is held constant and all other inputs adjust to their new cost-minimizing levels. We term these *net elasticities*:

$$\epsilon_{ij} = \left. \frac{d \ln X_i}{d \ln P_j} \right|_{Y=Y_0} \quad (8.5)$$

In this last price elasticity definition, the F level responds to the change in price  $P_j$ . In addition, we can link these two types of elasticities under the assumption of linear homogeneity of the sub-function 8.2:

$$\begin{aligned} \epsilon_{ij} &= \left. \frac{d \ln X_i}{d \ln P_j} \right|_{Y=Y_0} \\ &= \left. \frac{\partial \ln X_i}{\partial \ln P_j} \right|_{F=F_0} + \left. \frac{\partial \ln X_i}{\partial \ln F} \frac{\partial \ln F}{\partial \ln P_j} \right|_{Y=Y_0} \\ &= \epsilon_{ij}^* + \epsilon_{FF} \times S_{jF} \\ &= \epsilon_{ij}^* + (\gamma - 1) \times S_{jF} \end{aligned} \quad (8.6)$$

Where  $S_{j,F}$  is the cost share of the input j in the cost of producing F and  $\epsilon_{FF}$  is the own price elasticity of demand for capital knowledge services F along the isoquant  $Y = Y_0$ .

Finally, we define the third type of elasticity, the *expansion elasticity* or *scale elasticity*, as the difference between the two previous elasticities. Thus, we calculate this elasticity as follows:

$$\bar{\epsilon}_{ij} = \epsilon_{FF} \times S_{jF} = (\gamma - 1) S_{jF} \quad (8.7)$$

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In order to better understand the meaning of these elasticities, Berndt and Wood (1979 [19]) provide a graphical interpretation. To simplify, we assume that the master-function as well as the sub-function depend on only two inputs. For instance, we suppose that  $Y = Y(F; Q)$  where  $Q = Q(L; K)$  is another intermediate aggregate output (sub-function) of capital and labor and  $F$  is the aggregate output of knowledge factors, and we suppose that  $F = F(T; N)$  where  $T$  could stand for ICT capital and  $N$  for intangible capital. In addition, since we suppose perfect competition on each intermediate sector, the prices of the two intermediate outputs  $Q$  and  $F$  should equal their unit cost of production:

$$\begin{aligned} P_Q &= \frac{P_L L + P_K K}{Q(L; K)} \\ P_F &= \frac{P_T T + P_N N}{F(T; N)} \end{aligned} \tag{8.8}$$

We consider an initial situation characterized by an optimal cost-minimizing equilibrium given the input prices  $P_L, P_K, P_T, P_N$  and a final output  $Y = Y^*$ . According to this equilibrium, the level of use of the intermediate factors is defined in figure 8.1a by point  $E_i$  on the isoquant  $Y = Y^*$  where the slope of the iso-cost tangent ( $AA'$ ) is  $-P_Q/P_F$ . And in the same way, the level of the use of the inputs in the sub-sector  $F$  (respectively  $Q$ ) is defined by point  $S_i$  in figure 8.1b on the isoquant  $F = F_i^*$  (resp.  $M_i$  in figure 8.1c on the isoquant  $Q = Q_i^*$ ) where the slope of the iso-cost tangent ( $CC'$ ) is  $-P_N/P_T$  (resp.  $(UU')$  is  $-P_L/P_K$ ). Accordingly, the cost minimization of producing  $Y = Y^*$  leads to use  $T_i^*, N_i^*, L_i^*, K_i^*$  which correspond to an initial production of intermediate goods  $F_i^*$  and  $Q_i^*$ . Now supposing that following an innovation in the ICT sector, the price  $P_T$  of the input  $T$  decreases. First, for the  $F$ -isoquant in figure 8.1b, holding fixed the output of the knowledge activities at the initial level  $F = F_i^*$ , the new iso-cost tangent ( $DD'$ ) that matches the new price ratio  $-P_N/P_T$  is steeper than the previous one. Then, the equilibrium point  $S_i$  moves to  $S_1$ , leading to a gross substitution effect that is measured by  $\epsilon_{TT}^*$  and  $\epsilon_{NT}^*$ . Next, as  $P_T$  decreases, the cost of producing  $F$  decreases, as well as  $P_F$ . Consequently, for the master-function isoquant in figure 8.1a, the slope of the iso-cost tangent ( $-P_Q/P_F$ ) will decrease (becomes more negative) and thus the equilibrium point will move from  $E_i$  to  $E_f$  resulting in another substitution effect of  $F$  on  $Q$ , leading to an outward shift of the isoquant  $F = F_i^*$  to  $F = F_f^*$  (fig. 8.1b) and an inward shift of the isoquant  $Q = Q_i^*$  to  $Q = Q_f^*$  (fig. 8.1c). So the new optimal point of the use of the knowledge inputs moves to  $S_f$ , subsequently increasing the derived demand both for ICT (from  $T_1$  to  $T_f$ ) and intangibles (from  $N_1$  to  $N_f$ ) due to an expansion effect given by  $\epsilon_{TT}^{\bar{}}$  and  $\epsilon_{NT}^{\bar{}}$ . As shown in figure 8.1b, while both the substitution effect and the expansion

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effect increase the demand for ICT, these two effects work in opposite directions for the demand for intangibles. The total effect ( $S_i$  to  $S_f$ ) is then assessed by the net elasticities  $\epsilon_{TT}$  and  $\epsilon_{NT}$ . Thus, finally while ICT and intangibles are necessarily gross substitutes<sup>3</sup>, if the expansion effect is greater than the substitution effect ( $|\epsilon_{\bar{NT}}| > |\epsilon_{NT}^*|$ ), ICT and intangibles can be net complements as shown in this figure. In figure 8.1b we see that the decline in ICT prices has led to an increased demand for intangible assets.

Our aim is then to characterize the production function of this intermediate knowledge good, in order to highlight the economic complementarities that could exist between “knowledge accumulation” activities using a Cobb-Douglas master-function. In our case, the knowledge sub-function depends on more than two inputs; thus we can obtain gross complementarity between some of them. In fact, at least two inputs must be gross substitutes but we can obtain net complementarity between all knowledge factors.

For this purpose, we first evaluate the level of the factor F (or more precisely the level of  $F' = F \times A^{1/\gamma}$  since we can not separate the MFP ex-ante) from the final output and the use of the other factors. And secondly, we estimate the knowledge production function using a flexible specification without any need for an assumption on the substitutability between inputs.

### 8.3 Econometric specification

In our study, we proceed in two steps. The first step comprises of the assessment of the “knowledge sector’s” output and its unit price. For this purpose, we proceed by deduction under the previous assumption on the final good production function. Besides, we cannot dissociate F and MFP, therefore we consider a proxy variable  $F'$  so we may attribute the entire MFP to the knowledge sector.

We deduce  $F' = F \times A^{1/\gamma}$  as follows:

$$\ln(F') = \frac{1}{\gamma} [\ln(Y) - \alpha \ln(L) - \beta \ln(K)]$$

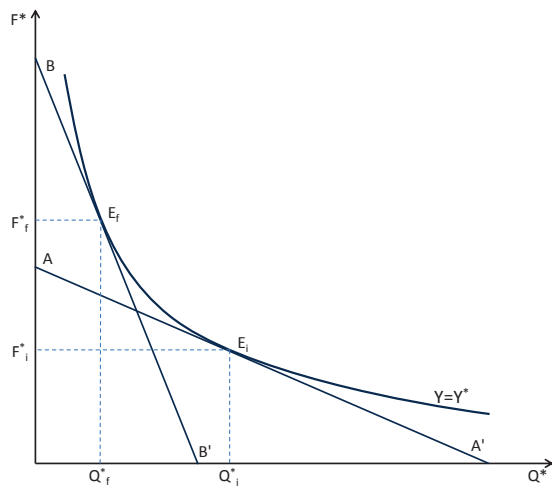
Through this way, we can deduce the unit cost of the “productivity factor”  $F'$  by dividing its cost by its measured volume:

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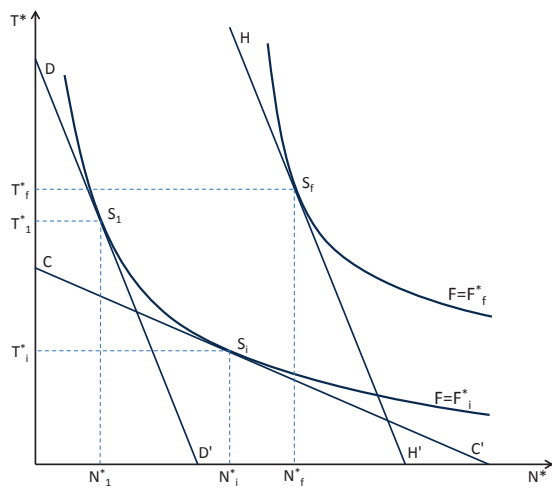
<sup>3</sup>It is no longer the case when the subfunction includes more than two inputs

Figure 8.1: Isoquants of production

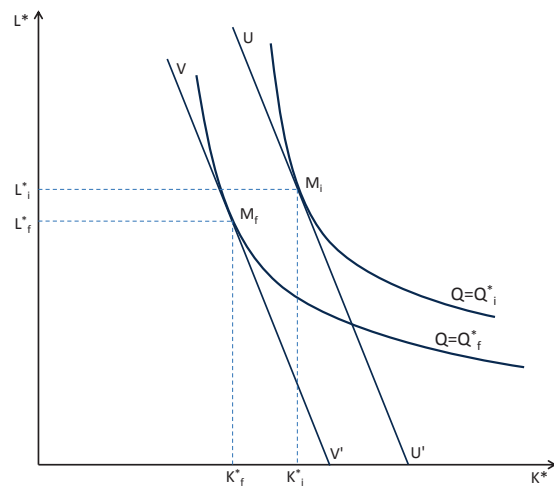
(a) Master function isoquant



(b) Knowledge subfunction isoquant



(c) Q isoquant



$$\begin{aligned}
 Cu_{F'} &= \gamma \times Y \times P_Y \times \exp\left(-\frac{1}{\gamma} [\ln(Y) - \alpha \ln(L) - \beta \ln(K)]\right) \\
 &= (w_{ICT}K_{ICT} + w_{CI}K_{CI} + w_{EC}K_{EC} + w_{IP}K_{IP}) \times \exp\left(-\frac{1}{\gamma} [\ln(Y) - \alpha \ln(L) - \beta \ln(K)]\right)
 \end{aligned}
 \tag{8.9}$$

Then, the second step consists in the specification and the estimation of the knowledge production function with the objective of minimizing production costs. Consequently, when  $Y$  and factor prices are exogenous, we can use the duality of the cost function on the function  $F$ . In order to identify the substitution possibilities or the complementarities that could exist between inputs, we estimate a translog function of the unit cost, based on such a dual approach. This specification could be defined as follows:

$$\ln(Cu_{F'}) = a + \sum_i a_i \times \ln(w_i) + \frac{1}{2} \sum_i \sum_j a_{ij} \times \ln(w_i) \times \ln(w_j)$$

with  $i, j = ICT, CI, EC, IP$

We add to this specification a time dimension in order to highlight exogeneous technical change. We, thus, obtain the expression below:

$$\begin{aligned}
 \ln(Cu_{F'}) &= a + \sum_i a_i \times \ln(w_i) + \frac{1}{2} \sum_{i,j} a_{ij} \times \ln(w_i) \times \ln(w_j) \\
 &\quad + a_t t + \frac{1}{2} a_{tt} t^2 + \sum_i a_{it} \ln(w_i) \times t
 \end{aligned}
 \tag{8.10}$$

Moreover, in order for this function to portray economic reality, it should comply some constraints that we will look at below.

### 8.3.1 The constraints and the final estimated model

**The monotonicity and concavity constraints** The cost function must be non-decreasing with respect to input prices and must be concave with respect to the vector of prices. In particular, the function must meet two properties:

- The cross-price effects must be symmetric and thus the matrix of second derivatives of the cost function must be symmetric. Therefore, the symmetry constraint implies:  $a_{ij} = a_{ji}, \forall i, j$
- Furthermore. the own-price effects must be non-positive. We will check this property using the negativity of the own-price elasticities.

**The constraint of homogeneity of degree one with respect to prices** The cost function must be homogeneous of degree one with respect to prices. This property means that if all input prices are multiplied by a scalar, then the total cost for an identical level of output is also multiplied by this factor.

The constraint of homogeneity of degree one in prices leads to:

$$\begin{aligned}
 \sum_{i=ICT,CI,EC,IP} a_i &= 1 \\
 \sum_{i=ICT,CI,EC,IP} a_{ij} &= 0, \forall j = ICT,CI,EC,IP \\
 \sum_{j=ICT,CI,EC,IP} a_{ij} &= 0, \forall i = ICT,CI,EC,IP \\
 \sum_{i=ICT,CI,EC,IP} a_{it} &= 0
 \end{aligned} \tag{8.11}$$

**The equations of the shares of each factor in the production cost** From the equation, we deduced the shares in the cost of production of the factor  $F$  for all factors by applying the Shepard lemma:

For  $i = ICT, EC, IP$ :

$$\begin{aligned}
 S_{iF} &= \frac{P_i X_i}{C_{F'}} \\
 &= \frac{P_i}{C_{F'}} \frac{\partial C_{F'}}{\partial P_i} \\
 &= \frac{P_i}{C_{F'}/F'} \frac{\partial C_{F'}/F'}{\partial P_i} \\
 &= \frac{\partial \ln(C_{F'})}{\partial \ln(P_i)}
 \end{aligned}$$

Then

$$S_{iF} = \frac{w_i K_i}{\sum_i w_i K_i} = a_i + \sum_{j=ICT,CI,EC,IP} a_{ij} \times \ln(w_j) + a_{it} \times t, \quad i = ICT,CI,EC,IP \tag{8.12}$$

And by construction, thanks to the previous constraints, the sum of the shares equals 1:

$$\begin{aligned}
 \sum_i S_{iF} &= \sum_i \left( a_i + \sum_{j=ICT,CI,EC,IP} a_{ij} \times \ln(w_j) + a_{it} \times t \right) \\
 &= \sum_i a_i + \sum_i \sum_j a_{ij} \times \ln(w_j) + a_{it} \times t \\
 &= 1
 \end{aligned}$$

**The final estimated function:** Consequently, imposing the constraints, the final system that we estimate becomes:

$$\left\{ \begin{aligned}
 \ln\left(\frac{Cu_{F'}}{w_{IP}}\right) &= a + a_{ICT} \ln\left(\frac{w_{ICT}}{w_{IP}}\right) + a_{CI} \ln\left(\frac{w_{CI}}{w_{IP}}\right) + a_{EC} \ln\left(\frac{w_{EC}}{w_{IP}}\right) \\
 &\quad + \frac{1}{2} \left( a_{ICTICT} \ln\left(\frac{w_{ICT}}{w_{IP}}\right)^2 + a_{CICI} \ln\left(\frac{w_{CI}}{w_{IP}}\right)^2 + a_{ECEC} \ln\left(\frac{w_{EC}}{w_{IP}}\right)^2 \right) \\
 &\quad + a_{ICTCI} \ln\left(\frac{w_{ICT}}{w_{IP}}\right) \ln\left(\frac{w_{CI}}{w_{IP}}\right) + a_{ICTEC} \ln\left(\frac{w_{ICT}}{w_{IP}}\right) \ln\left(\frac{w_{EC}}{w_{IP}}\right) + a_{CIEC} \ln\left(\frac{w_{CI}}{w_{IP}}\right) \ln\left(\frac{w_{EC}}{w_{IP}}\right) \\
 &\quad + a_{it}t + \frac{1}{2}a_{tt}t^2 + a_{ICTt} \ln\left(\frac{w_{ICT}}{w_{IP}}\right)t + a_{CI}t \ln\left(\frac{w_{CI}}{w_{IP}}\right)t + a_{EC}t \ln\left(\frac{w_{EC}}{w_{IP}}\right)t \\
 S_{ICT,F} &= a_{ICT} + a_{ICTICT} \times \ln\left(\frac{w_{ICT}}{w_{IP}}\right) + a_{ICTCI} \times \ln\left(\frac{w_{CI}}{w_{IP}}\right) + a_{ICTEC} \times \ln\left(\frac{w_{EC}}{w_{IP}}\right) \\
 &\quad + a_{ICTt} \times t \\
 S_{CI,F} &= a_{CI} + a_{CICI} \times \ln\left(\frac{w_{CI}}{w_{IP}}\right) + a_{ICTCI} \times \ln\left(\frac{w_{ICT}}{w_{IP}}\right) + a_{CIEC} \times \ln\left(\frac{w_{EC}}{w_{IP}}\right) \\
 &\quad + a_{CI}t \times t \\
 S_{EC,F} &= a_{EC} + a_{ECEC} \times \ln\left(\frac{w_{EC}}{w_{IP}}\right) + a_{ICTEC} \times \ln\left(\frac{w_{ICT}}{w_{IP}}\right) + a_{CIEC} \times \ln\left(\frac{w_{CI}}{w_{IP}}\right) \\
 &\quad + a_{EC}t \times t
 \end{aligned} \right. \tag{8.13}$$

### 8.3.2 Interpretation of the parameters

The aim of this chapter is to study the substitutions or complementarities that bind the factors of innovation. For this purpose, we try to assess the partial elasticities of substitution. We use, in particular, two common definitions of such elasticities. The first one is the Allen elasticity of substitution that provides qualitative information on the complementary or substitutable nature of the factors. The second one, called the Marshall elasticity, appraises the relative variation of the demand for a factor  $i$  with respect to the relative variation of the price of an input  $j$ , leaving the level of the output and the prices of the other inputs unchanged. As we already discussed this earlier in chapter 5, we thus briefly recall their definitions under to this new framework.



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**Gross Allen elasticity of substitution:** We note  $\sigma_{ij}^*$  the gross Allen elasticity between two factors  $i$  and  $j$  (the Allen elasticities are symmetric and accordingly  $\sigma_{ij}^* = \sigma_{ji}^*$ ). In the framework of a translog specification, this elasticity is defined as follows:

$$\sigma_{ij}^* = \frac{a_{ij} + S_{iF}S_{jF}}{S_{iF}S_{jF}} \quad i \neq j, \quad i, j = ICT, CI, EC, IP \quad (8.14)$$

It does not provide relevant quantitative evaluation but the sign highlights the substitution relationships between inputs:

- If  $\sigma_{ij}^* > 0$  the two inputs  $i$  and  $j$  are gross substitutes;
- If  $\sigma_{ij}^* < 0$  the two inputs  $i$  and  $j$  are gross complements;
- If  $\sigma_{ij}^* \rightarrow \infty$  the two inputs  $i$  and  $j$  are perfectly substitutable;
- If  $\sigma_{ij}^* = 0$  the two inputs  $i$  and  $j$  are perfectly complementary.

**Gross Marshall elasticity of substitution:** We note  $\epsilon_{ij}^*$  the gross Marshall elasticities representing the elasticities of the demand for the factor  $i$  with respect to the price of the factor  $j$ . This elasticity is defined by the following equation and can be related to the Allen elasticity via the multiplication by the share in the cost of the input whose price is changing:

$$\epsilon_{ij}^* = \frac{\partial \ln X_i}{\partial \ln P_j} = \sigma_{ij}^* \times S_{jF} \quad (8.15)$$

**Gross own-price elasticities:** In order to verify the non-positivity of the own-price effects of each factor on the cost function of the intermediate good F', we calculate the own-price elasticities of each "knowledge input" with respect to the production function of the good F'. The Allen and Marshall own-price elasticities could be written:  $\sigma_{ii}^* = \frac{a_{ii} + S_{iF}(S_{iF} - 1)}{S_{iF}^2}$  and  $\epsilon_{ii}^* = \frac{\partial \ln X_i}{\partial \ln P_i} = \sigma_{ii}^* \times S_{iF}$ . However, these own-price elasticities are not consistent with the real price elasticities of demand for these factors. These elasticities are, indeed, assessed in the framework of the intermediate production function and not with respect to the production function of the final good. In order to estimate the real price elasticities, we must take into account the elasticity of the factor F.

**Net elasticities:** According to section 8.2, we can deduce the net elasticities from the gross elasticities knowing that the master-function is a Cobb-Douglas one where the coefficients  $\alpha$  and  $\beta$  equal the

shares in the total cost of producing the final output  $Y$  of the labor input and the non-ICT tangible capital respectively.  $1 - \alpha - \beta$  is then equal to the share of  $F$  in this total cost of the production of  $Y$ . Thus:  $\epsilon_{FF} = 1 - \alpha - \beta - 1 = -\alpha - \beta = S_{FY} - 1$ , where  $S_{FY}$  is the cost share of the input  $F$  in the total cost of producing the final output  $Y$ . Therefore, we obtain the final net elasticities:

$$\begin{aligned}\epsilon_{ij} &= \epsilon_{ij}^* + \epsilon_{FF} \times S_{jF} \\ &= \epsilon_{ij}^* - (\alpha + \beta) S_{jF} \quad \forall i, j = ICT, CI, EC, IP \\ &= \epsilon_{ij}^* + (S_{FY} - 1) S_{jF}\end{aligned}\tag{8.16}$$

and

$$\begin{aligned}\sigma_{ij} &= \frac{\epsilon_{ij}}{S_{jY}} \\ &= \frac{\epsilon_{ij}}{S_{jF} \times S_{FY}} \quad \forall i, j = ICT, CI, EC, IP\end{aligned}\tag{8.17}$$

## 8.4 Empirical Results

### 8.4.1 The data

For this study, we use the same data as well as the same cost of use for each capital asset which we constructed in the previous chapter.

### 8.4.2 Estimation results

We estimated the temporal variations of  $S_{ICT,F}$ ,  $S_{CI,F}$  and  $S_{EC,F}$  translog cost-share equations (8.13), imposing separability with the other inputs in the final production using the Zellner method. Moreover, with respect to the previous description of the estimated function, we added dummy variables in order to take into account country specificities. As we only estimated the share's functions in time difference, the coefficients  $a_{i,t}$  are specific to each country. Moreover, according to the previous specification, we also add a control variable to take into account business cycles and we define it as one minus the rate of unemployment. The parameters relative to this adjustment are denoted as  $a_{i,u}$ . Furthermore, we add a dummy variable to take into account the dotcom crisis on the ICT factor (this variable  $\delta_{ICT,T_{2000}} = 1$  until 2001 and  $\delta_{ICT,T_{2000}} = 0$  after 2001<sup>4</sup>). Finally, the system is estimated over the period 1996-2005

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<sup>4</sup>ICT investments fall in 2001 with respect to 2000, so the growth rate of ICT capital used in production is affected in 2002.

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for eleven countries which gives us 98 observations<sup>5</sup>.

Table 8.1 gives the estimation results for the cost-share equations' parameters and the estimated gross and net elasticities are presented respectively in tables 8.2 and 8.3. Several comments can then be made in light of these results:

First, the negativity of the gross own-price Marshall elasticities (see table 8.2b) is consistent with the concavity constraint described above. We also necessarily have negative own-price elasticities on the macrofunction level and the constraint is automatically satisfied if it is satisfied in the sub-function.

According to our estimation, the gross own-price elasticities, with respect to their cost of use, are around -0.10 for ICT (without software) (between -0.09 and -0.11) as well as for Computerized Information (between -0.09 and -0.10) and around -0.15 both for Economic Competencies and Innovative Properties capital (the two are between -0.13 and -0.16). As for the final net elasticities, we find that they are between -0.22 and -0.38 for ICT capital, between -0.16 and -0.22 for CI, between -0.48 and -0.54 for EC and between -0.51 and -0.61 for IP.

Concerning the Innovative Property capital, which stands for R&D capital, these results are in line with the literature. Indeed, among the most recent studies, McKenzie and Sershun (2010 [157]) who study 9 OECD countries over the period 1979-1997, find an elasticity in R&D capital with respect to its user cost between -0.7 and -0.9 in the long run. Baghana and Mohnen (2009 [11]) estimate an elasticity of -0.19 for the Quebec, and Wilson (2009 [236]) -2.6 for the United States. Table 8.4 in the appendix sums up other recent papers on this topic and a more complete review can be found in Parsons and Phillips (2007 [182]).

On the other hand, regarding the ICT own-price elasticity, the economic literature is less rich. Cette and Lopez (2010, [45]) assess this elasticity to be around -2 in the early 1990s and closer to -1 in 2005. Tevlin and Whelan (2003, [215]) estimated the long-run elasticity of the computer capital stock with respect to the cost of capital over the period 1980- 1997 to be -1.6. Consequently, it seems that our results are lower than those in the economic literature.

However, we must be cautious when we compare our results to other studies. As we include intangible assets in the assessment of value added, we modify the user cost of capital and its evolution as well. Therefore, the estimated price elasticities are affected and this effect is more so for the elasticities of ICT as intangible investments seem to evolve in the same way as the ICT investments<sup>6</sup>.

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<sup>5</sup>We have 99 observations instead of 110 because we have estimated in time differences and in fact we have 98 observations due to the removal of an aberrant point in Portugal.

<sup>6</sup>Incidentally, the elasticities we obtain are lower in average than those found in chapter 5 but this comparison is

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Furthermore, the observation of the gross Allen elasticities of substitution, given in table 8.2a, allows us to establish the substitutability characteristics between the four groups of factors ICT, “Computerized Information” (CI), “Economic Competencies” (EC) and “Innovative Properties” (IP) in the sub-function.  $\sigma_{ICT,CI}^*$ ,  $\sigma_{ICT,EC}^*$  and  $\sigma_{ICT,IP}^*$  are positive for most countries and thus define ICT as a gross substitute of the intangible assets, in general. Admittedly two countries, France and Germany, behave differently compared to the others in term of the gross substitutability of ICT. However it should be noted that in these countries, the prices of the ICT investment decrease much less than in the others and this could arise from a methodological difference in quality adjustment in the price indices. If this is indeed the case, changes in investment volumes tend to be underestimated in these countries and hence the level as well as the growth of the ICT capital stock tend to also be underestimated. In this way, we can observe a small contribution of ICT capital deepening in France and Germany that seems to be inconherent with the others, especially in France where the quality adjustment in ICT investment prices is the lowest (see table 7.1 or figure 7.1). This observation tends to support this idea. In most cases,  $\sigma_{CI,IP}^*$  and  $\sigma_{EC,IP}^*$  are negative and suggest that IP is usually a gross complement of the other intangible assets. As for the elasticity between CI and EC,  $\sigma_{CI,EC}^*$ , the sign is not completely clear but these two factors seem to be complementary or at least weakly substitutable, except for Denmark, France and the United-Kingdom.

Finally, the net elasticities of substitution are all negative, showing net complementarities between all knowledge factors which implies that, in cases where we have gross substitutability, the expansion effect consistently dominates the gross substitution effect.

The empirical literature on this topic of the relationships between intangibles and ICT capital is very recent and the approaches are so different that it is difficult to compare them. In particular, while most found complementarity between ICT and intangible capital, the relationship with sub-components of intangible assets are more complicated to compare. For instance, Brynjolfsson et al. (2002 [39]), using their financial market based approach, find that each dollar of installed computer capital is coupled with between \$5 and \$10 of market value which indicates a strong complementarity with intangible assets, since they correspond to the difference between a firm’s market value and tangible assets. On the other hand, Cummins (2005 [61]) which uses “the analyst-based proxy and the GMM technique”, “finds no evidence of economically important intangibles associated with investment in intellectual

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nevertheless risky since we compare macro results to specific sectoral results.

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property or physical capital apart from IT". However, both its intellectual property and organizational capital do not match with our innovative properties and economic competencies respectively. Indeed, for him, intellectual property includes patents, trademarks, copyrights, brand names, secret formulas, advertising, etc. and the definition of organizational capital is based on IT<sup>7</sup> and is considered as an adjustment cost from IT investment. Finally, Lev and Radhakrishnan (2005 [151]) who examine the association between information technology expenditures and organization capital, also find that IT is strongly associated with organizational capital.

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<sup>7</sup>IT includes also softwares in its definition

Table 8.1: Estimation results

$a_{ICT,ICT}$	0.130*** (0.005)	$a_{ICT,t}^{AT}$	0.006** (0.002)	$a_{CI,t}^{AT}$	0.005** (0.002)	$a_{EC,t}^{AT}$	-0.011*** (0.002)
$a_{CI,CI}$	0.108*** (0.007)	$a_{ICT,t}^{DK}$	0.014*** (0.002)	$a_{CI,t}^{DK}$	0.011*** (0.002)	$a_{EC,t}^{DK}$	-0.017*** (0.002)
$a_{EC,EC}$	0.204*** (0.021)	$a_{ICT,t}^{FI}$	0.009*** (0.002)	$a_{CI,t}^{FI}$	0.000 (0.002)	$a_{EC,t}^{FI}$	-0.011*** (0.002)
$a_{ICT,CI}$	-0.018*** (0.004)	$a_{ICT,t}^{FR}$	0.003* (0.002)	$a_{CI,t}^{FR}$	0.006*** (0.002)	$a_{EC,t}^{FR}$	-0.004** (0.002)
$a_{ICT,EC}$	-0.048*** (0.004)	$a_{ICT,t}^{DE}$	0.006** (0.002)	$a_{CI,t}^{DE}$	0.003 (0.002)	$a_{EC,t}^{DE}$	-0.004* (0.002)
$a_{CI,EC}$	-0.039*** (0.007)	$a_{ICT,t}^{IT}$	0.010*** (0.002)	$a_{CI,t}^{IT}$	0.000 (0.002)	$a_{EC,t}^{IT}$	-0.007*** (0.002)
$a_{ICT,T_{2000}}$	0.004*** (0.001)	$a_{ICT,t}^{NL}$	0.009*** (0.002)	$a_{CI,t}^{NL}$	0.005** (0.002)	$a_{EC,t}^{NL}$	-0.007*** (0.002)
$a_{ICT,u}$	2.43E-03** (7.94E-04)	$a_{ICT,t}^{PT}$	0.025*** (0.002)	$a_{CI,t}^{PT}$	0.001 (0.002)	$a_{EC,t}^{PT}$	-0.021*** (0.002)
$a_{CI,u}$	9.24E-04 (7.82E-04)	$a_{ICT,t}^{ES}$	0.007*** (0.002)	$a_{CI,t}^{ES}$	0.005** (0.002)	$a_{EC,t}^{ES}$	-0.008*** (0.002)
$a_{EC,u}$	-1.02E-04 (7.50E-04)	$a_{ICT,t}^{SE}$	0.006*** (0.002)	$a_{CI,t}^{SE}$	0.001 (0.002)	$a_{EC,t}^{SE}$	-0.005** (0.002)
		$a_{ICT,t}^{UK}$	0.017*** (0.002)	$a_{CI,t}^{UK}$	0.002 (0.002)	$a_{EC,t}^{UK}$	-0.008*** (0.002)
Equation		R2	D.-W.				
Share of ICT		0.910	1.520				
Share of CI		0.748	1.525				
Share of EC		0.721	1.681				
Nb. of obs.		98					

Table 8.2: Gross Price Elasticities

(a) Allen elasticities (substitution or complementarity)

	$\sigma_{ICT,CI}^*$	$\sigma_{ICT,EC}^*$	$\sigma_{ICT,IP}^*$	$\sigma_{CI,EC}^*$	$\sigma_{CI,IP}^*$	$\sigma_{EC,IP}^*$
AT	-0.24	0.25	0.28	-0.83	-0.74	0.07
DK	0.36	0.00	-0.01	0.22	0.21	-0.10
FI	0.11	0.01	0.21	-0.28	-0.02	-0.01
FR	-0.08	-0.17	-0.26	0.16	0.10	0.13
DE	-0.19	-0.12	0.23	-0.70	-0.15	0.04
IT	0.41	0.33	0.20	0.00	-0.17	-0.19
NL	0.03	0.17	-0.03	0.02	-0.19	0.09
PT	0.04	0.47	0.24	-0.53	-1.19	-0.06
ES	0.57	0.30	0.38	-0.28	-0.12	-0.60
SE	0.23	-0.21	0.05	0.02	0.24	-0.05
UK	0.33	0.27	0.04	0.16	-0.10	-0.07

(b) Own-price Marshall elasticities

	$\epsilon_{ICT,ICT}^*$	$\epsilon_{CI,CI}^*$	$\epsilon_{EC,EC}^*$	$\epsilon_{IP,IP}^*$
AT	-0.10	-0.10	-0.14	-0.14
DK	-0.11	-0.09	-0.15	-0.15
FI	-0.11	-0.10	-0.15	-0.13
FR	-0.11	-0.09	-0.14	-0.14
DE	-0.11	-0.10	-0.15	-0.12
IT	-0.10	-0.09	-0.14	-0.15
NL	-0.11	-0.10	-0.13	-0.15
PT	-0.10	-0.10	-0.13	-0.16
ES	-0.09	-0.09	-0.16	-0.16
SE	-0.11	-0.09	-0.15	-0.13
UK	-0.10	-0.09	-0.14	-0.15

(c) Cross-price Marshall elasticities

	$\epsilon_{ICT,CI}^*$	$\epsilon_{ICT,EC}^*$	$\epsilon_{ICT,IP}^*$	$\epsilon_{EC,ICT}^*$	$\epsilon_{CI,IP}^*$	$\epsilon_{IP,ICT}^*$	$\epsilon_{EC,CI}^*$	$\epsilon_{CI,EC}^*$	$\epsilon_{CI,ICT}^*$	$\epsilon_{EC,IP}^*$	$\epsilon_{IP,EC}^*$
AT	-0.02	-0.05	0.07	0.05	0.12	0.06	-0.06	-0.25	-0.31	0.03	0.02
DK	0.06	0.06	0.00	0.00	-0.01	0.00	0.04	0.06	0.08	-0.04	-0.03
FI	0.01	0.02	0.00	0.00	0.09	0.04	-0.03	-0.07	-0.01	0.00	0.00
FR	-0.01	-0.01	-0.06	-0.02	-0.11	-0.03	0.02	0.05	0.04	0.05	0.04
DE	-0.02	-0.03	-0.03	-0.02	0.11	0.04	-0.06	-0.17	-0.07	0.02	0.01
IT	0.05	0.10	0.10	0.08	0.07	0.05	0.00	0.00	-0.06	-0.06	-0.06
NL	0.00	0.01	0.06	0.03	-0.01	0.00	0.01	0.01	-0.07	0.03	0.03
PT	0.00	0.01	0.16	0.12	0.07	0.06	-0.04	-0.18	-0.38	-0.02	-0.02
ES	0.08	0.18	0.07	0.09	0.13	0.12	-0.04	-0.06	-0.04	-0.20	-0.13
SE	0.03	0.03	-0.05	-0.03	0.02	0.01	0.00	0.01	0.10	-0.02	-0.01
UK	0.05	0.07	0.09	0.05	0.01	0.01	0.02	0.05	-0.03	-0.02	-0.02

Table 8.3: Net Price Elasticities

(a) Allen elasticities (substitution or complementarity)

	$\sigma_{ICT,CI}$	$\sigma_{ICT,EC}$	$\sigma_{ICT,IP}$	$\sigma_{CI,EC}$	$\sigma_{CI,IP}$	$\sigma_{EC,IP}$
AT	-11.93	-8.18	-5.82	-23.80	-14.39	-19.03
DK	-4.84	-9.74	-7.48	-8.36	-5.17	-19.77
FI	-6.64	-8.99	-5.22	-13.36	-6.46	-16.87
FR	-8.25	-10.79	-8.86	-8.44	-5.59	-14.39
DE	-11.00	-12.26	-6.02	-21.22	-8.82	-18.87
IT	-6.54	-9.12	-8.28	-15.65	-11.75	-30.34
NL	-6.80	-6.84	-6.51	-9.19	-7.15	-14.00
PT	-10.78	-6.57	-7.49	-23.20	-21.69	-25.69
ES	-4.11	-8.66	-5.66	-18.58	-10.27	-38.02
SE	-3.62	-7.43	-4.13	-6.57	-2.85	-11.86
UK	-3.84	-5.25	-5.35	-6.98	-5.77	-15.02

(b) Own-price Marshall elasticities

	$\epsilon_{ICT,ICT}$	$\epsilon_{CI,CI}$	$\epsilon_{EC,EC}$	$\epsilon_{IP,IP}$
AT	-0.29	-0.16	-0.51	-0.57
DK	-0.26	-0.24	-0.50	-0.54
FI	-0.27	-0.20	-0.48	-0.58
FR	-0.22	-0.22	-0.52	-0.56
DE	-0.26	-0.18	-0.48	-0.61
IT	-0.32	-0.21	-0.51	-0.53
NL	-0.25	-0.20	-0.53	-0.54
PT	-0.34	-0.17	-0.54	-0.52
ES	-0.38	-0.22	-0.47	-0.53
SE	-0.24	-0.22	-0.47	-0.55
UK	-0.28	-0.21	-0.51	-0.51

(c) Cross-price Marshall elasticities

	$\epsilon_{ICT,CI}$	$\epsilon_{CI,ICT}$	$\epsilon_{ICT,EC}$	$\epsilon_{EC,ICT}$	$\epsilon_{ICT,IP}$	$\epsilon_{IP,ICT}$	$\epsilon_{CI,EC}$	$\epsilon_{EC,CI}$	$\epsilon_{CI,IP}$	$\epsilon_{IP,CI}$	$\epsilon_{EC,IP}$	$\epsilon_{IP,EC}$
AT	-0.08	-0.24	-0.23	-0.16	-0.23	-0.12	-0.67	-0.16	-0.56	-0.09	-0.74	-0.53
DK	-0.09	-0.09	-0.29	-0.17	-0.30	-0.13	-0.25	-0.15	-0.20	-0.09	-0.78	-0.60
FI	-0.09	-0.14	-0.27	-0.19	-0.26	-0.11	-0.40	-0.17	-0.32	-0.08	-0.84	-0.51
FR	-0.13	-0.12	-0.40	-0.15	-0.41	-0.12	-0.32	-0.13	-0.26	-0.09	-0.66	-0.54
DE	-0.10	-0.18	-0.30	-0.20	-0.28	-0.10	-0.51	-0.19	-0.42	-0.08	-0.89	-0.46
IT	-0.06	-0.12	-0.21	-0.17	-0.21	-0.15	-0.35	-0.15	-0.30	-0.12	-0.77	-0.68
NL	-0.09	-0.14	-0.29	-0.14	-0.29	-0.13	-0.39	-0.13	-0.32	-0.10	-0.63	-0.59
PT	-0.06	-0.23	-0.18	-0.14	-0.19	-0.16	-0.64	-0.13	-0.55	-0.13	-0.65	-0.71
ES	-0.05	-0.11	-0.16	-0.22	-0.15	-0.15	-0.34	-0.21	-0.28	-0.12	-1.03	-0.69
SE	-0.09	-0.09	-0.31	-0.19	-0.29	-0.10	-0.28	-0.16	-0.20	-0.07	-0.84	-0.50
UK	-0.07	-0.10	-0.23	-0.14	-0.24	-0.14	-0.31	-0.13	-0.26	-0.11	-0.67	-0.66



## 8.5 From input complementarity to strategic complementarity

As this study aims to reveal the complementarities that exist between ICT producer's innovations (inventions) and ICT user's innovations (co-inventions) empirically, we now present how the adopted specification is suitable for this demonstration. For this purposal, we first briefly recall the different cases of complementarities and then we justify how these input complementarities that we obtained in our estimations reflect the strategic complementarities that characterize a GPT.

There are different notions of complementarity depending on the variables on which we focus. They are not dissociated but we cannot consider them as equivalent either. In our case, we must distinguish two types of complementarity, the complementarity between inputs or goods and the strategic complementarity. The first relates to the utility of two economic goods whereas the second relates to the activities of two economic agents.

The *complementarity between factors* (or goods) is certainly the most common concept: two factors (or goods) are complementary when the productivity of one factor (the utility of one consumption good) is increased by the use of the other factor, or needs the use of the other factor, and reciprocally. This is the relationship we established between knowledge inputs.

The *strategic complementarity* was originally established in a game theory framework by Bulow, Geanakoplos and Klemperer (1985, [41]). It characterizes a situation where the decisions of two or more players mutually reinforce one another. Conversely, when they mutually offset one another, they are defined as *strategic substitutes*. In our study, we are particularly interested in how one player's innovation affects the other players; so we are more specifically interested in strategic complementarity in research and, more largely, in intangible investments. Consequently, we restrict this type of complementarity to the concept of "*innovation incentive complements*"<sup>8</sup>. This concept corresponds, in fact, to the links between GPT producers and GPT users, as identified by Bresnahan and Trajtenberg (1995, [31]) and represented by the two externalities, vertical and horizontal, that we described in chapter 6 section 6.2 on page 217.

Actually, this concept of "*innovation incentive complements*" defines a situation where profits in an industry are increased by innovation in a different industry and vice versa. Subsequently, as the profit is higher, the incentive to invest in R&D with the aim of earning this rent is higher. The innovation in a sector increases, therefore, the incentives to invest in R&D in the other sector. Furthermore, the

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<sup>8</sup>See also Haruyama (2006, [117]) for a description of "*R&D incentive complements and substitutes*"

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fact that an industry benefits partly from the fruits of R&D of the other without paying the cost led Bresnahan and Trajtenberg to relate these complementarities to externalities. Thus, at first glance, this situation should not be compatible with the hypothesis we made of a perfectly competitive market. Nevertheless, the way we separate production activity from innovation allows us to partly express this property on the macro level.

First, innovation by ICT producers decreases the ICT capital cost of use<sup>9</sup>, and consequently, as the expansion (or scale) effect is higher than the substitution effect, both the return from the total innovative activity (the return of producing  $F$ ) and the return from all the innovative inputs (among them, organization and R&D) are increased in the using industries. In fact, the expansion elasticity reflects the innovation opportunities generated by the decrease in the ICT price. This relationship matches the arrows 1i and 1j in figure 6.1 on page 219, that is to say, the first vertical externality.

Second, the production function of the innovative activity means that innovation by ICT users is a corollary to the use of ICT. Therefore, the more the using industries increase their innovative activities (the more  $F$  is increased at the macro level), the higher their demand for ICT. So, ICT producing industries are encouraged to invest in innovation via a “demand driven” mechanism<sup>10</sup>. This relationship matches the arrows 2i and 2j in figure 6.1, that is to say, the second vertical externality.

Consequently, the complementarities between knowledge factors, ICT and intangible capital, deduced from the cross price elasticities between them, reflect, indeed, the strategic complementarities that could exist between ICT-producers and ICT-users. In this way, the specification used here is appropriate to model the vertical relationships in the GPT-related mechanisms.

Finally, and this is one of the limits of our model, admittedly, the more ICT using industries innovate ( $F$  is increased), the more ICT producing industries will invest in research in return; but, if we have constant returns to scale in all the sectors, including ICT producers, the increase of the factor  $F_{ICT}$  does not lead to a decrease in the cost of the ICT investment<sup>11</sup>. Since we did not specify a

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<sup>9</sup>Even though, in the short run (in the case of “one shot” innovation), it tends to increase the asset specific capital loss  $g_{ICT,t} = \frac{P_{ICT,t}^I - P_{ICT,t-1}^I}{P_{ICT,t-1}^I}$ . In the long run, with a constant rate of ICT innovation, we have  $g_{ICT,t} = constant =$

$g_{ICT}$  and the equation 7.2 on page 246 leads to  $w_{ICT,t+1} - w_{ICT,t} = \delta (P_{ICT,t+1}^I - P_{ICT,t}^I)$ , thus the more the rate of ICT innovation is high, the more  $P_{ICT}^I$  decreases and the more  $w_{ICT}$  also decreases.

<sup>10</sup>If the production function of ICT producing industries is the same as the macro production function:  $Y = AF^\gamma L^\alpha K^\beta$ , when  $Y$  increases because of a higher demand, this sector increases all its input

<sup>11</sup>If the price of ICT investment goods are adjusted for quality the volume of ICT capital should correspond to a volume in efficiency units and the production of the ICT industry is measured in efficiency units as well. When we say that ICT investment prices do not decrease, in reality we say that the price of one efficiency unit of ICT capital does not decrease.

particular ICT producing industry, the dotted arrows 3i and 3j in figure 6.1 are not endogenized in our model and the horizontal externalities are, thus, not entirely laid bare by this specification. It remains, now, to complete the mechanism for horizontal relationships with the introduction of increasing social returns from ICT innovations.

## 8.6 Conclusion

The previous chapter showed that the integration of intangible expenditures as capital leads to a better explanation of productivity growth by reducing the importance of the MFP contribution. Moreover, the new source of growth model confirms the importance of the contribution of information and communication technologies and of intangible assets during the last decade. However, the framework of a simple Cobb-Douglas curbs the scope of the study. Indeed, ICTs are now widely accepted as General Purpose Technologies and the features of such technologies, which are at the origin of their ability to generate growth, are not taken into account in such a framework. In particular, one of their main properties is that they must be considered as enabling technologies in the sense that they do not bring about a self-sufficient solution but generate innovation opportunities, subject to additional complementary investments. Consequently, in order to assess their real role in contemporary growth, we have to take these features into account. That is why we intend, here, to highlight the relationships that exist between innovative activities to provide us with key so we can integrate GPT mechanisms in a macro-economic model.

In this study, innovative activities are considered in a relatively broad sense where they do not necessarily consist in R&D. In addition to R&D, we include investment in communication and information equipment (ICT), in computerized information (CI), and also in assets that we call economic competencies (EC) which group together expenditures on organization and on brand equity. As these expenditures are made in order to increase the performance of future production, we have seen in chapter 6 that it is necessary to consider them as capital. Furthermore, with the choice of a flexible form of the production function, the aim of the model described here is precisely to evaluate the interdependence of these innovative investments.

The main results of the study show that, for the European countries in the sample, even though ICT are gross substitutes of the other “knowledge inputs”, in the sense that to produce a given level of knowledge, a firm can partially arbitrate between the use of ICT and intangible assets. Lower

ICT prices create enough innovation opportunities to stimulate investments in other intangible assets. Moreover, the specification of the knowledge production function underlines the rise in the demand for ICT capital when the level of knowledge is increased. Therefore, considering that the decrease of ICT prices is a consequence of innovation by ICT producers, our estimations show that ICT producers and the whole economy (considered as ICT user), are “*strategic complements*” or more exactly “*innovation incentive complements*”. Thus, our specification appears appropriate for the modelling of the two vertical interactions between ICT-using and -producing industries identified by Bresnahan and Trajtenberg (1995 [31]) since the complementarities studied in this section match the concept of innovation complementarity developed in the framework of a GPT.

What is more, comparing our results with the current state of the art is difficult both because of the methodological heterogeneity and because of the sparsity of studies on intangible assets. Nevertheless, we can note the following initial observations. The literature on R&D price elasticities, which is the most documented point of our study, is in line with our results. On the other hand, it seems that we underestimated the ICT own-price elasticity with respect to other studies. However, this discrepancy could stem from the consideration of intangibles as capital. Concerning the final net complementarity between ICT and intangible capital, it seems to be in keeping with the rare existing studies on this topic. But a difference remains in the fact that we find complementarities between ICT and all intangible assets as well as between all intangibles, while other studies tend to point out a complementarity between ICT and organizational capital, which is included in economic competencies in our study, rather than between other assets.

In addition, a drawback of this model is that it does not integrate the cumulative aspect of capital and its intertemporal dimension, since we consider all factors as variable inputs. Such a flaw could be corrected with the estimation of function considering quasi-fixed capital, as we did in chapter 5. However, this specification reduces the number of observations for our estimation, given that the size of the time series is already low and, moreover, we could not define all the assets as quasi-fixed capital. Another second limitation of this specification is that it does not take into account knowledge externalities and increasing returns and, therefore, it does not explain the decrease in output price via the accumulation of knowledge but via the decrease of the input prices.

In this case, without a specific production function for ICT, we cannot yet explain the link between intangible investment and the fall in ICT prices. Therefore, something is missing to close the loop between ICT producers and all ICT users. In order to connect the users between them, we need to

## CHAPTER 8. EMPIRICAL EVIDENCE ON STRATEGIC COMPLEMENTARITY

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specify how ICT prices react to the increase in innovation in the producer sector. Therefore this, such reaction cannot be explained using the assumption of constant returns to scale. For this, we could adopt constant or increasing social returns of capital inputs (tangible and intangible), ( which could be introduced in such a model by the addition of *knowledge spillovers*, using, for instance, patent citations (see Jaffe, Trajtenberg and Romer 2005, [127]).

Finally, even though there is still room for improvement especially because of the weak number of data and aware of the limitation of the robustness of such assessment, this chapter provides a first compelling solution on how to model the impact of ICTs as a GPT. Here we have shown that this model fits the mechanisms of technological opportunities created by GPT and the vertical strategic complementarities that characterize a General Purpose Technology.

## 8.7 Appendix

Table 8.4: R&amp;D (IP) price elasticity in literature

Study	Country	Method	Sample Period	RD Price Elasticity
<i>Mulkay &amp; Mairesse (2011)</i>	France	Panel firm data	1978-2007	-0.4 (Long Run)
<i>McKenzie &amp; Sershun (2010)</i>	OECD countries	9 OECD countries	1979-1997	-0.2 to -0.3 (Short Run) -0.7 to -0.9 (Long Run)
<i>Baghana &amp; Mohnen (2009)</i>	Quebec	Panel firm data	1997-2003	-0.14 (SR) -0.19 (LR)
<i>Wilson (2009)</i>	US	51 states	1981-2002	-1.7 (SR) -2.6 (LR)
<i>Lokshin &amp; Mohnen (2007)</i>	Netherlands	Panel firm data	1996-2004	-0.3 (SR) -0.7 (LR)
<i>Parson &amp; Phillips (2007)</i>		Literature Review		-1.09 Median LR -1.22 Average LR
<i>Bernstein &amp; Mamuneas (2006)</i>	US	4 manuf. Industries	1954-2000	-0.12 to -1.33
<i>Dagenais, Mohnen &amp; Therrien (2004)</i>	Canada	Panel firms data	1975-1992	-0.07 (SR) -1.09 (LR)
<i>Poot et al (2003)</i>	Netherlands	Panel firm data	1996-1998	-0.11 (SR) -1.12 (LR)
<i>Independant Expert Group (2003)</i>		Literature Review		-0.85 Median
<i>Bloom, Griffith &amp; van Reenen (2002)</i>	9 OECD countries	9 OECD countries	1979-1997	-0.14 (SR) -1.09 (LR)
<i>Hall &amp; Van Reenen (2000)</i>		Literature Review		-0.25 to -2.0 (LR)



## Chapter 9

# General Conclusion

Information and Communication Technologies taken as General Purpose Technologies provide a very valuable viewing angle to analyse recent productivity growth in western economies. On one hand, the economic literature shows that ICT capital deepening has largely contributed to the productivity growth evolution during the latest thirty years in US and Europe as well as that it was a major source of the gap between them. On the other hand, GPT's properties widen the impact of ICT potential and describe the mechanisms through which these technologies can become an engine of growth.

According to the economic literature, the apparent impact of the ICTs on labour productivity took place in three main stages: (i) Before 1995, the economic impact of ICT innovation was confined to ICT producers and the growing share of service industries affected by Baumol's disease curtailed the increase in productivity growth. (ii) Between 1995 and 2000, productivity was relaunched in the US but not in Europe. In particular, the US productivity growth was mainly driven by a "within industry" process where the highly progressive ICT-producing industries represented a larger share and where there was a higher productivity growth in ICT using industries than in Europe. (iii) After 2000 and the dotcom crisis, ICT investments fell all over the world but labour productivity measured by national accountants continued to grow in the U.S. suggesting that ICT are not the only growth factor. Meanwhile, Europe "remained at the station".

We have seen that, in such a context, some economists developed theoretical models that describe these stages. All these models are based on the concept of General Purpose Technologies that are defined by the three main features that formed the basis of this thesis and that are regularly mentioned in the document:



## CHAPTER 9. GENERAL CONCLUSION

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1. they offer large possibilities for development;
2. they are ubiquitous;
3. they provide wide technological complementarities.

The consequences of these features are that they induce strong and generalised externalities between the GPT producers, which may be considered as basic inventors, and widespread GPT users, which are the co-inventors of GPT applications, as well as between GPT users themselves. This results in a situation of innovation strategic complementarity between these sectors in the sense that GPT basic inventions improve the benefits of the users and, conversely, the innovations in GPT applications, made by a GPT user, improve the returns of the GPT producing industries and of the other GPT users. The negative side of these externalities is that they involve coordination problems and create a lot of inertia in the economic system. Thus, when things evolve favorably, a long term dynamic develops consisting of large-scale efforts in research activities whose social and private marginal returns attain high levels. In the other case, the system is likely to be trapped into a very sub-optimal level of research investments in both types of sectors.

Therefore, throughout this thesis, we focused on the following questions:

1. Can ICTs be really considered as GPT?
2. How can ICT be modelled as GPT?
3. Are ICTs partly responsible for the productivity gap between Europe and the United States? In that case, can GPT properties explain the weakness in Europe with respect to the United States?

For this, we sought to provide empirical evidence of each GPT characteristic and we pointed out the differences between regions according to the GPT feature taken into account and/or the involved externalities.

The main results and contributions of this thesis are summed up in the following section.

## 9.1 Main conclusions

### 9.1.1 Capturing Information and Communication Technologies as General Purpose Technologies

Until now, there is no real demonstration that shows satisfactorily that ICT may be taken as GPT and even, until recently, the idea was controversial. Firstly, in the initial step of ICT diffusion, we saw positive impact in only a few sectors, especially in ICT producing industries. Secondly, economists struggled to show the enabling properties of ICT, failing to demonstrate that ICT innovations may lead to complementary innovations in downstream sectors. There are in fact two main reasons for this failure. The first is due to the difficulties in defining what to include the framework of “one” GPT in “the digital revolution”. The semiconductor, the computer, internet? Is each one a GPT individually or are they all one GPT together? Bresnahan and Trajtenberg (1995 [31]) provide a rigorous definition of a General Purpose Technology but not of what is a technology. The second reason is due to measurement problems and the fact that traditional data are not relevant when highlighting such radical change.

**Defining the GPT framework** As far the question of the definition of the unity of a GPT is concerned, in this thesis we adopted the following approach which is determined by the definition of the field of basic inventions and complementary co-inventions:

- The basic-inventions of GPT are constituted by the set of the applications of scientific knowledge for one general practical purpose.
- Whereas co-inventions are inventions made possible subsequently to the implementation of the basic inventions and answer this question: Now that we can perform this general practical purpose much more efficiently, how can we change the production process or output?

In order to illustrate these definitions of inventions and co-inventions, we use the case of the electricity and the ICT in table 9.1 as examples.

In our approach, in the case of electricity, we consider as basic inventions all inventions that aim to improve the ability to provide and use (transform) energy everywhere. Therefore, both the dynamo and the unit drive system may be considered as basic GPT inventions. Co-invention are constituted in this case by all inventions made possible subsequently to previous basic inventions, so here they are the replacement of machines in the factory, the new maintenance procedures, etc..

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Table 9.1: Examples of GPT

	<b>Electricity</b>	<b>ICT</b>
<i>General Practical Purpose</i>	<i>Provide and use energy everywhere</i>	<i>Manipulate information everywhere</i>
<b>Basic GPT inventions</b>	the dynamo, the unit drive system, etc.	the semiconductors, process that reduce the cost of semiconductors, the computer, the mouse internet, the world wide web, etc.
<b>Co-inventions</b>	the replacement of machines in the factory, new maintenance procedures, continuous production process, public lighting, etc.	the new online services (online sales, free music), the enterprise resource planning systems (ERP), better banking systems, scientific simulations with supercomputer, etc.

Similarly, in the case of ICT, we define as basic inventions all inventions that aim to improve the ability to provide and manipulate information everywhere. So semiconductors, computer, internet, etc. are, for us, all basic ICT inventions and co-inventions are constituted by new online services, enterprise resource planning system, etc..

From this point of view, when we consider a new GPT, in reality we are looking at a new wave of new applications of scientific knowledge directed towards one general practical purpose. This conception of GPT is therefore slightly different from the one described by Bresnahan and Trajtenberg (1995 [31]) where the GPT is the semiconductor and the downstream co-inventions are hearing aids, radios and TVs, computers, CT scanners or automobile engine control systems. Our alternative approach has no real implication on their theoretical results but it has a much greater impact on empirical attempts to find evidence that ICT is a GPT. Indeed, when considering their conception of invention and co-invention, the field of application and coinvention is restricted as in their example only manufacturing industries use semi-conductors (such as *Manufacturing of electrical equipment goods* or *Office machines*) and, above all, services sectors are not defined as application sectors of GPT. In addition, their field of co-invention is also too limited as this conception underestimates intangible innovation. Therefore, this practical approach leads us to (i) firstly deduce a non generality of purpose of ICT (the semiconductor) and, (ii) secondly, to largely underestimate the possibilities for co-inventions and thus the enabling feature of ICT, by ignoring a large number of the channels leading to co-invention.

**Measurement difficulties** In view of the definition of ICT inventions and co-inventions, throughout the thesis we point out that the assessment of the economic impact of ICT is arduous because of measurement problems with many different sources.

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First, ICT are themselves arduous to measure since, principally, the strong technical change in ICT makes it difficult to make a quality adjustment in the measurement of the volume of production or the volume of the investment.

Secondly, ICT co-inventions can come in many forms and are often invisible and, in addition, their determinants are also hard to capture. On one hand, the diffusion of ICT led to the creation of new services that did not have found, at the time, a business model and, therefore, do not appear in economic production data (internet related services for instance). On the other hand, co-inventions may be either inventions of new goods (new cars that embed ICT) or organizational innovations. While the first type of innovation may often be associated with accounted R&D expenditures and knowledge externalities revealed by patent data, the second type of innovation is more often the result of expenditures on other types of intangible assets, such as computing information or human capital.

Therefore, all these factors make any empirical assessment very difficult since available data are not suitable for the analysis of all the involved mechanisms. For instance, while patent data are relevant for the assessment of research productivity in ICT industries or for evaluations of knowledge externalities, these data are largely inadequate to provide evidences of all GPT properties. In particular, it is useless to capture co-inventions of new organizations that constitute a large share of ICT co-inventions as well as a main remedy for Baumol's disease in service sectors. That is why, according to Nordhaus (1997 [167]), official data "miss the most important technological revolution in history".

In this regard, in chapter 6 we point out that national accounts ignore most intangible expenditures while these are the main factors for co-invention. Furthermore, it is very important to take into account all categories of intangibles since the large variety of ICT users leads to very different ways to develop co-inventions or new ICT applications. While certain types of co-inventions are mainly the result of relatively well identified R&D expenditures in downstream sectors, others are the result of largely less identified intangible expenditures that cover, in particular, expenditure in market research, advertising, training, organizational structures, databases or software. Among these intangibles, only software is well accounted for.

In addition, as Corrado et al. (2005 [56]) explain, intangible expenditures must be taken as investment since they are made in order to enhance future production. However, only software was recently capitalized in national accounts so that more than 80% of intangible expenditures are considered as intermediate consumption. This greatly influences our perception of output and productivity growth.

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**ICT is definitely a GPT** From this conceptual framework, we are now able to confirm that ICT fills the three GPT features established by Bresnahan and Trajtenberg (1995 [31]):

1. First, the idea that ICT are very progressive is confirmed by the share of R&D allocated to this field (almost 20% in Europe and more than 25% in the US) and their weight in patent data (often more than 30%) compared to their economic weight (only between 4% and 6% of the value added in private sector). Furthermore, the rapid decrease in ICT investment prices adjusted for quality, with falls of more than 10% per year according to different national accounts and the period, points to a strong technical progress in that field as well.
2. Chapter 4, which deals with the diffusion of ICT across economic sectors, highlights the wide diffusion of ICT capital. Nevertheless, we must distinguish three types of sector: (i) ICT-producing industries; (ii) ICT-using industries that are constituted by the most ICT intensive using industries not included in the ICT producing industries and (iii) non-intensive ICT industries including the remaining industries. Among the ICT-using industries, the service sectors take a significant place.
3. The third part of this thesis deals with what is probably the most important GPT feature but, notwithstanding, the least documented in terms of empirical studies. The main reasons for this lack of statistical analysis are those mentioned above. The main results of this study show that, for the European countries in the sample, lower ICT prices create enough innovation opportunities to stimulate investments in other intangible assets. Moreover, the specification of the knowledge production function points out the rise in the demand for ICT capital to increase the level of knowledge. Therefore, considering that lower ICT prices are a consequence of innovation by ICT producers, our estimations show that ICT producers and the whole economy (considered as an ICT user), are “*strategic complements*” or more exactly “*innovation incentive complements*”. Our specification is thus capable of capturing the vertical interactions between ICT-using and -producing industries identified by Bresnahan and Trajtenberg (1995 [31]) since the complementarities studied in this section match the concept of innovation complementarity and the enabling feature developed in the framework of a GPT.

**Modelling ICT as GPT** We have thus seen that ICT as GPT is hard to capture: as the users of a GPT are numerous and belong to many different manufacturing and service sectors and as their

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use takes many different forms (intermediate consumption, productive capital, research tools, final consumption), we must consider many spheres of influence of this technology acting through different means. In particular, ICT as GPT yield:

- Knowledge externalities towards technologically close sectors (such as non-ICT electrical goods)
- Rent externalities towards user sectors (this externality allows to an agent to benefit from R&D expenditures through the purchase of a good which is R&D intensive<sup>1</sup>)
- Strategic complementarities in broad sectors:
  - Computers may be used in the final good to improve its quality (integrated GPS in cars)
  - Computers enhance the R&D performance (nuclear research in the 1960s)
  - Computers increase organization possibilities (ERP: enterprise resource planning systems<sup>2</sup>)
  - Computers lead to new services (GDS: global distribution systems<sup>3</sup>; online retailing)

All these externalities result in a situation of innovation strategic complementarity between ICT-producers and ICT-users, in the sense that innovation by one of two sectors increases profits and research incentives of the other one.

In view of this description, graph 9.1 depicts the way we must model ICT as GPT. In particular, this graph highlights the fact that there is no (or very poor) knowledge spillover between ICT industries and service industries. Therefore, the ICT enabling feature towards services does not take this channel.

### 9.1.2 A great challenge for Europe

This GPT framework seems to have been well exploited in the United States but it has not been the case in Europe. In particular, we have seen that Europe was not only weak at inventing ICT but also at using it and at benefiting from the ICT enabling potential. Nevertheless, we saw that this weakness of Europe is not homogenous across countries.

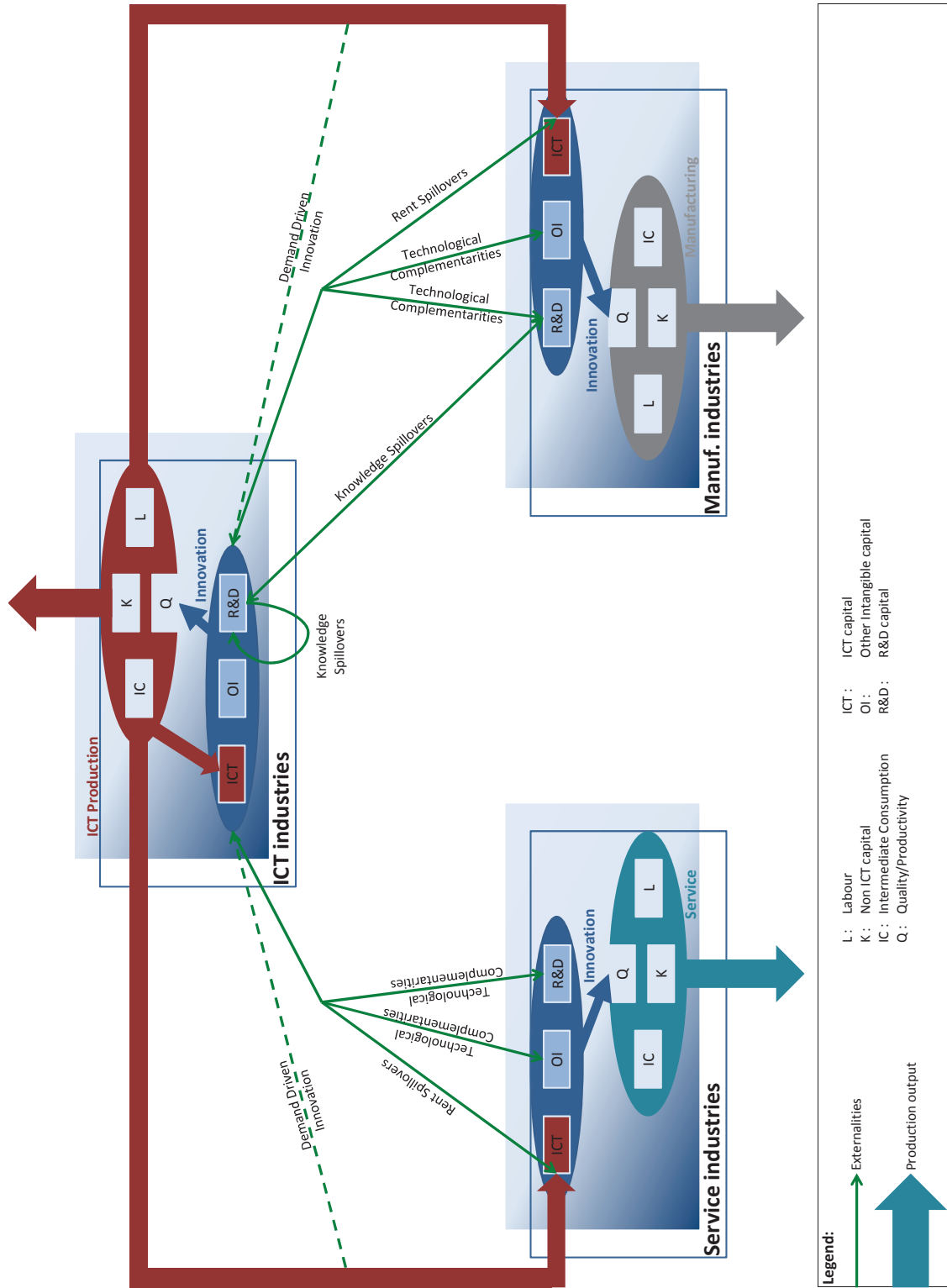
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<sup>1</sup>Nevertheless, as they are often tied to price measurement problems, rent spillovers are often not considered as “real knowledge spillovers” but rather as a measurement errors.

<sup>2</sup>Well known enterprises that provide such business software are the European firm SAP and the American Oracle

<sup>3</sup>These are computerized systems used to store and retrieve information and conduct transactions related to air travel

Figure 9.1: Modelling ICT as GPT



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**The United States was better at inventing ICT** U.S. has been a driving force in all stages of ICT invention, thanks to several elements. First, the US benefited certainly from inherent specificities such as a great domestic market with a single language. However, they also have created a favorable environment for innovation in the digital area with high and sustain public investments in R&D and infrastructures and early antitrust lawsuit. Moreover, their ability to involve many different types of agents such as universities, firms or individual entrepreneurs and to carry out a military-civilian transfer of knowledge created a leverage effect. In this way, agents involved in military projects were able to capitalize on their experience and subsequently they were able to develop civil applications (Supercomputers, SABRE, NSFNet) and highly innovative firms were founded or have grown, such as Bell, IBM, Cray Research Inc., Cisco Systems etc..

On the contrary, Europe failed to establish an enabling environment for innovation and for developing firms in that field. On one hand, by adopting a strategy of secrecy concerning the knowledge acquired during the Second World War in coding and computer science until 1975, the United Kingdom did not catalyse the process of innovation and the creation of enterprise in that field. On the other hand, later, the project to build a competitive European computer industry like Airbus did not succeed.

Nevertheless, not all European experiences were failures. Indeed, despite the fact that European countries did not manage to position themselves as real leaders, Europe was not been completely overtaken by the US. Furthermore, though some of the paths taken by European countries were not sustainable, they provided valuable knowledge in other contexts. In particular, even if the cost of obsolescence of the Minitel was high with the arrival of Internet in France, the experience based on the use of such technology was largely transferable to the use of Internet, since the services offered by both systems were very close.

Even today, despite several competitive European enterprises, the US are still leader in this field, followed by Japan. However this European backwardness does not seem unsurmountable.

### **ICT diffusion is greater in the US but this is not a sufficient explanation for its lead**

In chapter 4, we reviewed the economic literature on the EU-U.S. productivity gap and the main conclusions are that:

On the macroeconomic level, the economic literature on the source of labour productivity agrees on the identification of the three stages described above and the prominent role played by the ICT



## CHAPTER 9. GENERAL CONCLUSION

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in the US productivity resurgence during the period 1995-2000. Moreover, most studies agree on the fact that the productivity gap between US and Europe is attributable to the slower emergence of the knowledge economy, representing ICT capital deepening and the variation of the MFP, in Europe.

With the sectoral approach, Van Ark et al. (2003 [229]) show that U.S.-EU divergence comes from two “within industry” effects which result in: (i) a bigger ICT producing industry in US whose productivity growth is very high; (ii) higher productivity growth in ICT producing industries in US. In other words, the productivity gap is not due to an evolution of the economic structure. Nevertheless, in the long run, this may no longer be the case and the improvement in productivity in ICT using sectors may lead to an increase in the importance of these sectors at in the long term.

Therefore, according to the literature, producers or heavy users of ICT, are responsible for the largest part both of the productivity growth resurgence in United States in the late 1990s and of the US-EU divergence. In addition, these sectors also represent the biggest impact of ICT diffusion. We thus focused, in chapter 5, on these sectors that are the following<sup>4</sup>:

- *Electrical and Optical Equipment* (ICT producer);
- *Transport, Storage and Telecommunications* (which is an ICT producing industry in the “container and content” approach);
- *Wholesale and Retail Trade* (ICT-using sector);
- *Finance, Insurance, Real Estate and Business Services* (ICT-using sector).

As we take non-ICT capital into account as a quasi-fixed factor, i.e. a factor that cannot be instantaneously adjusted, we characterized countries with respect to their distance from the optimum use of factors using a definition of the capital use rate. The underlying idea is that the European incapacity to cure Baumol’s disease may result from adjustment rigidities of certain factors, especially of capital whose depreciation rate is low.

We find that non-ICT capital in the United States is relatively well adjusted in all types of sectors whereas Japan is among the most adjusted countries in ICT container and content industries but not in the intensive ICT using services. On the European side, the United Kingdom appears to have improved the adjustment of its capital over the period but the behavior of the other countries is heterogenous and

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<sup>4</sup>The sectors taken into account are more larger than it should be (in particular, instead of the sector *Telecommunication services*, we use the more aggregated sector *Transport, Storage and Telecommunications*) but we used this aggregated level because of data availability.

## CHAPTER 9. GENERAL CONCLUSION

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differs according to the sector. This misadjustment seems to provide some explanation of the lower performance in *Wholesale and retail trade* in France and in *Finance, insurance, and other business services* in Germany. However, it does not appear determinant in the poor performance of Italy and Spain .

In addition, the general trend to capital adjustment after 2000 in the user sectors supports Gordon's idea of productivity growth based on profit-driven cost-cutting and the role of the flexibility of the economy by shifting resources.

Finally, the post-dotcom crisis story highlights the need for a more complete explanation than a simple ICT-centered story. For this purpose, the enabling feature of the GPT provides a very good complementary explanation.

**Intangibles and the weakness of Europe** In the third part of the thesis, the introduction of intangible assets that are a major determinant of the potential impact of ICT diffusion, revealed that, over the period 1996-2005, not only European productivity performances were heterogeneous among countries, but the ranking of the European countries according to their labor productivity growth was almost the same as the ranking of the contribution of the knowledge economy<sup>5</sup>. In our sample, three countries displayed high deficiency in the knowledge economy. These countries are Italy where the knowledge contribution to labor productivity growth is negative (-0.6 % points), Portugal (where the contribution of knowledge is only 0.11% points) and Spain (0.30% points), whereas in the eight other countries this contribution range from 0.93% points in Denmark to 2.75% points in Sweden.

Furthermore, the rupture, that occurred with the dotcom crisis, reveals the solidity of knowledge based economies whereas symptoms of the "Olive Belt" disease appear to worsen after that. These results suggest, thus, that European economic performance is more likely to strengthen in laggard economies through the increase in knowledge capital. We also note that the capitalization of intangible investments increases their procyclicality mechanically with respect to GDP growth. Consequently, depending on whether they are procyclical or counter-cyclical with respect to GDP measured by national accounts, they should respectively tend to amplify or compress the measured amplitude of economic fluctuations.

In Gordon's words, concerning the adoption of ICT, "Europe remains at the station" but a train may hide another, and indeed, the ICT train rolls with the intangibles train, such that Europe misses

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<sup>5</sup>Knowledge economy includes ICT and intangible capital deepening, labor composition and MFP.

both trains. The ICT problem hides a much larger problem: that of the techno-economic paradigm shift which may be harmful in the long term. In this perspective, the awareness of the information issue in Europe must be linked to the issue of R&D and other intangible investments. Certainly, the Europe 2020 strategy (European Commission, 2010 [54]) holds, in its objectives, both a constituent on R&D investment, aiming to reach 3% of GDP in R&D investment in Europe, and a constituent on ICT, with the European Digital Agenda (European Commission, 2010 [55]), but these two objectives should be coordinated and must integrate, in addition, intangible assets in a broader consideration than only research investments.

### 9.2 Discussion and Future research

The assessments made in this thesis have limitations and there is still room for further research in the field of capturing a GPT. We identify the following limitations that are by no means exhaustive but we consider important.

**Improving measurement** The first point to improve concerns the economic data.

First we should construct sectoral data on intangible assets. This is necessary to carry out much more detailed analysis on the sectoral level. Indeed, the third part of the thesis is limited to a macroeconomic approach whereas a sectoral approach, distinguishing intensive ICT using industries and non intensive using industries or services and manufacturing industries, would have allowed us to determine the complementarity between ICT and intangibles much more precisely.

Secondly, we should take into account other ICT inputs rather than just ICT capital: for instance quality adjustments of given sectors with respect to the incorporation of ICT. Taking into account ICT as intermediate consumption or the ICT included in “non-ICT capital” assets, such as in CNC<sup>6</sup> machine or robots, may benefit the analysis of manufacturing industries. For instance, it may be relevant for the analysis of the Japanese robotic industry or the German machinery industry.

Finally, measuring emerging countries should be relevant in studies of international trade in ICT.

**Improving growth explanation and designing incentives for factors that enhance ICT impact** In the third part of the thesis, we used source of growth models using a Cobb-Douglas

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<sup>6</sup>Computer Numerical Control

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production function with a unit substitution elasticity between inputs. Nevertheless, in chapter 8, we showed complementarity between innovative inputs. Therefore, in order to better explain labour productivity growth we must take into account these complementarities and use another production function instead of the Cobb-Douglas function.

Another area to investigate relates to designing incentives for increasing intangible and ICT investments as well as to assess the leverage effect of potential subsidies in that field. For this, a sectoral approach is obviously necessary to distinguish the impact of incentives for the different intangible assets. In fact, incentives for R&D investments may impact manufacturing industries rather than services while, on the contrary, incentives for economic competency assets may impact service industries more.

Investigating the question of country specificities in terms of market size, financial institutions, product market regulation, labour market institutions, political unity or other country's features may also constitute another interesting approach in order to determine enable environments for intangible investments.

A great and arduous field of research may also be needed to determine who captures the value added in global supply chains of a GPT. This issue has begun to be tackled by some economists who describe the case of some ICT goods (see for instance Dedrick et al., 2010 [71] and 2011 [72] or Ali-Yrkko et al., 2011 [6]).

**Improving modelling for policy assessment** Finally, the integration of the mechanisms described in this thesis in large sectoral economic models is another important area of research. Such models are already used to assess R&D policies at European level (see for instance Brécard et al. 2006 [30], Soete 2010 [210] and Zagamé, 2010 [238]). In view of the importance of ICT in recent western economic growth, these models should take into account the specific properties of this technical change. They are crucial to capture because of their centrality in explaining the complex relationships between innovation, productivity and economic growth on macro-sectoral level. These models will allow us to assess ICT and intangible oriented policies as well as to understand how ICT could reshape the economy depending on different policy scenarios. These policy studies are of interest because we must of course, encourage the development of knowledge but we must also be alert so we identify the emergence of these opportunities in order to determine the directions in which research efforts should be made. For instance, the following policies may be assessed using large scale economic models:

- Increase incentives for intangible investment in the “Olive Belt”.

## CHAPTER 9. GENERAL CONCLUSION

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- Enhance the ICT industry in Europe with a better coordination of the different ICT industries (Semiconductor, hardware, software, internet, telecommunication equipment,...) often located in different countries.
- Create incentive for innovation by adapting the orientation of policy depending on the sectoral composition of the country (smart specialisation in intangible investment, Foray, David and Hall, 2009 [78]):
  - Grant more importance to economic competencies in countries that are more specialized in services and
  - Grant more importance to innovative properties in more industrial countries such as Germany?
- Counter cyclical intangible incentive policy (see Fougeyrollas et al., 2010 [79] for an example of such simulation). for this purpose we must determine whether all intangible assets have the same cyclical behaviour (are they all as procyclical as R&D).

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# Résumé

**Introduction** Le progrès technique est reconnu comme une source majeure de l'accroissement de la productivité du travail à long terme. L'idée, relativement ancienne, a été notamment développée et popularisée par J.A. Schumpeter à travers son mécanisme de destruction créatrice (1942 [203]), processus dans lequel les entrepreneurs cherchent et réalisent des innovations qui rendent obsolète les technologies courantes. Plus récemment, après avoir justifié la croissance économique de long terme par l'existence de rendements non décroissants (Solow, 1956 [211]; Romer, 1986 [191]), les théoriciens de la croissance endogène ont abordé l'innovation comme une activité économique et formalisé le comportement de recherche par les espérances de rentes de monopole, ces dernières constituant le rendement des coûts de recherche (Romer, 1990 [192]; Grossman et Helpman, 1991 [104]; Aghion et Howitt, 1992 [4]). Toutefois, si ces formalisations apportent des outils précieux pour décrire une croissance de long terme continue, elles ne suffisent pas pour expliquer les discontinuités de la croissance. Or l'histoire économique révèle davantage un sentier de croissance par vague qu'un processus continu avec parfois même des reculs. Plusieurs types de cycles sont différenciés suivant leur période, notamment Kitchin et Juglar décrivent des cycles courts (quelques années) tandis que Kuznets et Kondratieffs décrivent des cycles plus longs (d'une dizaine d'années pour le premier à 50-60 ans pour le second). L'histoire économique occidentale du XXème siècle révèle en effet de tels cycles. En particulier concernant les cycles longs, les Etats Unis ont observé une accélération de la croissance de la productivité du travail au cours des années 1920 appelée "la Grande vague" et cette "Grande vague" n'atteignit l'Europe qu'à l'après-guerre. Durant la période suivante, connue sous le nom des Trentes Glorieuses, l'Europe entama un rattrapage des Etats Unis avec un niveau de croissance de la productivité du travail élevé. Ensuite, après les premiers chocs pétroliers, ces économies connurent une longue période de stagnation de la productivité qui ne repartira qu'à l'aube du XXIème siècle aux Etats-Unis, l'Europe semble alors être encore à la peine.

Les économistes ont longtemps cherché les déterminants de ces vagues successives et non simultanées. Parmi eux J.A. Schumpeter explique ces cycles de long terme par l'émergence d'innovations majeures engendrant des grappes d'innovations. Plus tard, des historiens économistes soulignèrent le rôle clef qu'ont joué certaines technologies telles que l'imprimerie, la machine à vapeur ou la dynamo, dans les vagues successives d'innovations et de croissance (Landes, 1969 [146] ou Rosenberg, 1982 [193]). En outre, ces observations surviennent à une période marquée par l'émergence rapide et la large diffusion d'une grappe d'innovations autour de ce qui est appelé les Technologies de l'Information et de la Communication (TIC). Seulement, si au début des années 1990 la "Révolution Numérique" semble être de plus en plus visible dans les biens qui nous entourent, elle ne se fait pas remarquer dans les performances économiques. La situation laisse alors place aux sarcasmes tels que la fameuse phrase de Solow sur le paradoxe de productivité: "Nous voyons les ordinateurs partout autour de nous sauf dans les statistiques de productivité<sup>7</sup>".

Cependant, certains économistes reprennent le cas de la dynamo et l'électricité au début du siècle et font l'analogie avec le cas des TIC. En particulier, David (1991 [67]) rappelle que la dynamo, qui a été inventée en 1900, n'a fait, dans un premier temps, que remplacer la machine à vapeur en laissant l'architecture de production inchangée. Ce n'est que dans les années 1920, après l'invention du moteur unitaire et la réorganisation des processus de production que les effets sur la productivité sont alors apparus.

Dans ce cadre, le concept de Technologie Générique (TG), développé par Bresnahan et Trajtenberg (1995 [31]), offre les outils théoriques nécessaires pour comprendre les mécanismes sous-jacents à de tels changements structurels qualifiés de changements de paradigme techno-économique (Freeman and Perez 1986 [83]). Les propriétés des TG qui font d'elles un moteur de croissance sous condition d'un environnement favorable sont que ces technologies possèdent<sup>8</sup>:

1. un fort potentiel de développement;
2. un fort potentiel d'ubiquité (technologie ubiquitaire);
3. un fort potentiel à générer des innovations complémentaires (technologie habilitante).

Ces propriétés génèrent alors un gisement d'externalités que le régulateur doit prendre en compte pour

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<sup>7</sup>Robert Solow dans une déclaration pour le New York Times Book Review, 12 juillet 1987, p36

<sup>8</sup>Lipsey, Carlaw et Bekar (2006 [152]) identifient quatre propriétés; par rapport à leur approche nous regroupons les deux propriétés de "larges possibilités d'utilisation" et "d'applicabilité dans beaucoup de secteur" dans la propriété de "fort potentiel d'ubiquité".

conduire l'économie à sa croissance optimale qui n'est, de fait, pas spontanée. Ces externalités sont principalement de deux types:

1. Des externalités verticales lient les producteurs aux utilisateurs de la TG: l'innovation dans la TG génère des opportunités d'innovations pour les secteurs utilisateurs.
2. Des externalités horizontales lient les utilisateurs entre eux: l'innovation par un utilisateur tendant à accroître la demande pour la TG augmente l'incitation du producteur de la TG à innover à nouveau et, par retour, bénéficie aux autres utilisateurs.

Ces externalités conduisent alors à une situation de "complémentarité stratégique"<sup>9</sup> entre les producteurs et les utilisateurs de la TG. Ainsi, cette approche implique-t-elle la prise en compte de deux catégories d'innovations: une première constituée des innovations sur la TG, appelées "inventions basiques", et une seconde catégorie incluant toutes les innovations rendues possible par la TG et qui amplifient son effet, appelées "co-inventions".

Jusqu'à présent, il n'y a pas eu réellement de démonstration satisfaisante de la validité de l'hypothèse selon laquelle les TIC peuvent être considérées comme une technologie générique et l'idée est parfois même controversée. Par ailleurs si le mécanisme vertueux semble avoir été enclenché aux Etats-Unis depuis la seconde moitié des années 90, en revanche, l'Europe, à l'instar de ce qui s'est passé au début du XXème siècle, ne semble pas parvenir à suivre la marche. L'objet de cette thèse est donc de trois ordres. Le premier est de déterminer les voies empiriques qui permettent d'identifier les propriétés des TG dans le cas des TIC; le deuxième objectif, qui découle directement du premier, consiste à fournir des indications précises sur la manière dont nous pouvons modéliser les interactions entre les producteurs et les utilisateurs de TIC dans la perspective de modèles macro-sectoriels; et enfin, le troisième objectif consiste à expliquer les faiblesses de l'Europe vis-à-vis des Etats Unis à la lumière de ces mécanismes, c'est-à-dire à comparer ces deux pays dans leur capacité à exploiter les propriétés d'une telle technologie. Nous organisons donc la thèse autour des trois propriétés mentionnées ci-dessus.

## **Part I: Le progrès technique dans le secteur des TIC**

**Chapitre 2** Nous débutons cette thèse par l'analyse de l'innovation dans l'industrie des TIC. Pour cela nous procédons en deux temps. Dans un premier temps nous effectuons une brève revue

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<sup>9</sup>Concept défini par Bulow et al. (1985 , [41]) qui caractérise une situation dans laquelle les décisions de deux joueurs ou plus les renforcent les uns des autres.

historique des principales innovations qui ont marqué l'évolution des TIC. En outre, nous tentons d'identifier les facteurs du succès américain dans ce domaine par rapport aux pays européens et les raisons pour lesquelles les Etats-Unis ont été une force motrice à toutes les étapes du développement des TIC. Nous avons rappelé que, si les Etats-Unis ont bénéficié de caractéristiques intrinsèques au pays telles que la taille du marché domestique, ils ont aussi su développer un contexte favorable à l'innovation dans ce domaine grâce, en particulier, à des investissements publics soutenus (militaires pour beaucoup) en R&D et en infrastructure ainsi qu'à des législations favorables à la concurrence. En outre, leurs capacités à impliquer des acteurs d'horizon divers tels que des acteurs gouvernementaux, des universités, des entreprises privées et des entrepreneurs individuels ainsi qu'à assurer le transfert des connaissances militaires vers des applications privées ont généré un puissant effet de levier. Ainsi, les agents impliqués dans des projets militaires ont-ils été en mesure de bénéficier de leur expérience et de leurs recherches effectuées dans ce cadre afin de développer le marché civil (notamment dans le domaine des supercalculateurs, des logiciels ou d'Internet).

Les pays européens n'ont pas réussi à établir un environnement aussi favorable à l'innovation et, surtout, au développement d'entreprises dans ce domaine. D'une part, la stratégie du secret adoptée par le Royaume Uni jusqu'en 1975 sur les connaissances acquises dans le domaine des ordinateurs durant la Seconde Guerre Mondiale n'a pas pu catalyser l'innovation dans le domaine. D'autre part, le projet de construction d'une industrie informatique européenne compétitive, à la manière d'Airbus, n'a pas abouti par manque de continuité d'effort et de gouvernance.

Néanmoins, l'expérience Européenne dans ce domaine ne se réduit pas à des échecs puisque, si ils n'ont pas toujours été leaders, les pays européens n'ont pas été totalement absents et ont apportés leur lot d'innovations majeures dans le domaine des TIC. Par ailleurs, si certaines innovations n'ont pas réussi à s'imposer comme standard, elles ont permis de bénéficier d'une expérience précieuse. Le Minitel a, par exemple, permis à la France d'acquérir une expérience dans le domaine des services en ligne en partie transposable à Internet.

Dans la seconde partie de ce chapitre, nous étudions les données contemporaines sur l'innovation dans l'industrie des TIC, à savoir en particulier les dépenses en R&D et les données de brevets (notamment de citations de brevets). Nous montrons que cette industrie, représentant environ 5% de la valeur ajoutée pour 20% à 25% des dépenses en R&D du secteur privé dans les pays étudiés, témoigne d'une activité d'innovation très élevée confirmant la première propriété des TG. Nous montrons aussi que les Etats Unis ont une activité d'innovation plus performante que l'Europe et semblent avoir une

capacité plus élevée à générer et à absorber les externalités de connaissance dans le domaine des TIC. Par ailleurs, nous montrons que les données de citations de brevets ne permettent pas de montrer que les TIC vérifient les deux autres propriétés d'une TG (ni qu'ils ne les vérifient pas). En particulier, nous rappelons, d'une part, que l'ubiquité de la technologie n'implique pas l'ubiquité de la connaissance créée et utilisée pour développer cette technologie et, d'autre part, que la complémentarité d'innovation n'implique pas non plus des externalités de connaissances. Par conséquent, la non généralité des connaissances utilisées pour le développement des TIC ne remet pas en cause leur qualité de technologie générique.

**Chapter 3** Dans le second chapitre de cette première partie, nous passons en revue les problèmes de mesure qui découlent de la rapidité et de la nature du changement induit par de telles technologies. Nous identifions deux grandes catégories de difficultés à surmonter.

La première catégorie tient à l'identification des biens et services reliés à la technologie, c'est-à-dire des formes sous lesquelles la technologie apparaît dans les intrants et dans la production ainsi que de la façon dont elle est identifiée dans les systèmes de comptabilité nationale. Cela implique, d'une part, d'identifier un secteur de production des TIC et, d'autre part, d'identifier les facteurs de production qui incorporent les TIC. La seconde catégorie de difficultés relève de la séparation volume-prix dans les données économiques et de l'ajustement de la qualité.

En ce qui concerne la définition du secteur TIC, deux approches peuvent être adoptées: une approche "contenant", incluant uniquement les industries qui produisent le vecteur de l'information (autrement dit, les équipements TIC uniquement), et une approche "contenant et contenu" ajoutant à la première approche les industries qui fournissent l'information. Par ailleurs, nous identifions trois obstacles à la mesure de la production directement ou indirectement liés à l'apparition des TIC ou, d'une façon plus générale, d'une nouvelle TG. Le premier obstacle est l'impossibilité d'anticiper la nature des changements majeurs, le deuxième découle de l'absence de marché pour certains services rendus par la technologie (externalités) et le troisième obstacle résulte de l'apparition de nouvelles organisations des marchés (marchés bifaces par exemple).

En ce qui concerne les TIC comme intrant, nous avons vu que les bases de données disponibles nous permettent de les identifier uniquement lorsqu'ils prennent la forme de capital qui peut être physiquement isolé des autres types de capital. Par conséquent nous ne prenons en compte ni les TIC utilisés en consommation intermédiaire (e.g. GPS dans la fabrication des voitures) ni ceux incorporés

dans le capital (ordinateur interne à une machine à commande numérique par exemple).

Enfin, le problème de la séparation volume-prix est principalement abordée sous deux approches: l'approche au "*coût des facteurs*" qui examine le progrès technique dans le processus de production du bien et l'approche aux "*services producteur*" qui considère l'accroissement des performances du bien. Nous déduisons finalement que l'approche aux "*services producteur*" est plus adaptée à nos besoins.

## **Part II: Les TIC en tant que technologie ubiquitaire**

**Chapter 4** Le quatrième chapitre porte sur l'observation de la diffusion des TIC en tant qu'investissement dans l'économie. Nous procédons alors en deux étapes. Dans une première étape nous effectuons une analyse descriptive des données d'investissement en TIC. En particulier, nous décrivons les spécificités des pays et des secteurs dans ce domaine. Nous observons alors une accélération de ces investissements durant la période 1995-2000 suivie d'un retournement de tendance et d'une baisse de l'investissement, plus ou moins forte en fonction des pays, après l'éclatement de la bulle internet. Dans cette section, nous décrivons aussi la dominance de la composante "équipement informatique" dans la croissance du capital TIC et l'hétérogénéité sectorielle en termes de taux de croissance de ces investissements.

Dans la seconde étape, nous effectuons une revue des études évaluant l'impact économique direct des TIC par la méthode de comptabilité de la croissance. Nous observons un consensus de la littérature sur l'existence de trois phases dans l'adoption des TIC. Une première phase durant laquelle seuls les producteurs de TIC bénéficièrent du progrès technique dans ce domaine tandis que certains utilisateurs voient même leur productivité décroître et sont alors touchés par la "maladie de Baumol". La seconde phase peut se décrire, selon des termes empruntés à Helpman et Trajtenberg, comme la période de la récolte des fruits de la technologie où la croissance de la productivité se généralise et s'accroît particulièrement dans la plupart des industries utilisatrices des TIC. La troisième phase, montrant une persévérance de la croissance de la productivité aux Etats-Unis malgré la chute des investissements en TIC après 2000, met alors en évidence la nécessité de compléter l'explication centrée uniquement sur le développement et la diffusion des TIC. Par ailleurs, l'analyse de la littérature nous amène à distinguer trois catégories de secteurs: les secteurs producteurs de TIC, les secteurs intensifs dans l'utilisation des TIC et les autres.

**Chapter 5** Au chapitre 5, nous nous intéressons au comportement de demande de facteurs dans quatre secteurs qui sont, soit producteurs de TIC, soit intensifs en utilisation de TIC. Nous estimons une forme flexible de fonction de coût (duale à la fonction de production) qui n'implique aucune hypothèse sur la substituabilité des facteurs. Ces estimations nous fournissent une première élasticité prix du capital TIC par rapport à son coût d'usage et, en particulier, nous obtenons une élasticité d'environ -0.6 pour les secteurs fortement utilisateurs de TIC et de -0.3 pour le secteur producteur.

Par ailleurs, dans la spécification adoptée de la fonction de coût estimée, nous imposons une rigidité sur le capital non TIC dont le taux de déclassement est nettement supérieur à celui du capital TIC. Nous trouvons que la capacité à ajuster les facteurs de façon optimale diffère selon les secteurs et les pays. En particulier, le niveau du capital quasi-fixe en France et en Allemagne reste plus éloigné de son optimum qu'aux USA et au Royaume-Uni dans les services utilisateurs des TIC: *Finance, assurance, immobilier et autres services aux entreprises* et dans *Commerce de gros et de détail*. Cependant, cette spécification ne permet pas de donner des explications sur l'écart de croissance de la productivité du travail dans les pays européens les moins performants que sont en particulier l'Italie et l'Espagne.

Pour cela la troisième propriété des TG, c'est à dire leur capacité à générer des opportunités d'innovation, nous apporte une indication précieuse. Nous étudions donc cette propriété appliquée aux TIC dans la partie suivante.

### **Part III: Les TIC en tant que technologie habilitante**

**Chapter 6** Dans cette troisième partie, nous commençons par rappeler la littérature théorique portant sur les TG et, en particulier, nous décrivons les mécanismes dit de "co-invention" sous-jacents à de telles technologies qui sont à l'origine de leur force motrice. Les "co-inventions" consistent en des innovations rendues possibles grâce au développement d'une TG. C'est alors un cercle vertueux qui se crée entre ces co-inventions et les innovations dans la TG et qui permet aux TG de devenir un moteur puissant de croissance. Nous replaçons ensuite cette littérature dans le cadre des TIC et, dans ce contexte, nous identifions la nature de ces "co-inventions" vouées à amplifier l'effet des innovations TIC. Nous montrons qu'une grande partie de ces innovations sont de nature organisationnelle et ne sont, par conséquent, pas visible à travers les données économiques traditionnelles. Nous expliquons alors les raisons pour lesquelles les dépenses intangibles réalisées pour aboutir à ces innovations doivent être prises en compte dans les systèmes de comptabilité nationale et doivent être considérées de façon similaire à des investissements. La littérature identifie en particulier trois grandes



catégories d'actifs intangibles: (i) les données informatisées (logiciels et bases de données); (ii) les actifs propres d'innovation (principalement le stock R&D) et (iii) les compétences économiques (constituées des valeurs de marques, des compétences organisationnelles et du capital humain). Une nouvelle conception de la comptabilité de la croissance incluant ces actifs émerge alors dans la littérature.

**Chapter 7** Au chapitre 7, nous appliquons un modèle de source de croissance défini par Corrado, Hulten et Sichel (2006 [57]) à onze pays européens en utilisant des données provenant des bases EU KLEMS et INNODRIVE. Nous montrons qu'inclure les actifs intangibles dans la comptabilité accroît globalement la mesure de la croissance de la productivité du travail et réduit la part "inexpliquée" de cette croissance, cette dernière étant constituée de la croissance de la productivité multifactorielle (PMF). Nous montrons, en outre, que cette approche apporte un bon éclairage sur l'hétérogénéité des pays européens dans le sens où nous observons un lien entre la contribution des actifs intangibles et la performance économique des pays et en particulier aux extrêmes. Ces résultats étant cohérents avec la littérature existante. Cependant, l'analyse du tournant induit par la crise de 2000 suggère que ce type de modèle, basé sur une fonction de production Cobb-Douglas, doit être encore amélioré. En effet, si ce type de modèle permet de prendre en compte simultanément les investissements en TIC et en actifs intangibles, ces derniers reflétant les co-inventions, il ne révèle pas leur complémentarité et même suppose une substituabilité unitaire entre eux.

**Chapter 8** Ainsi, consacrons-nous le dernier chapitre de cette thèse à l'évaluation des complémentarités potentielles entre ce que nous appelons les intrants d'innovation, à savoir le capital TIC et le capital intangible. Pour cela, nous définissons une fonction de production à deux niveaux. Le premier niveau, ou le niveau supérieur, prend la forme d'une Cobb-Douglas à trois facteurs: le travail, le capital tangible non-TIC et un "facteur agrégé de productivité". Le niveau inférieur est le niveau où ce dernier facteur est produit par une sous-fonction flexible à quatre facteurs: le capital TIC (hors logiciel) et les trois types d'actifs intangibles. L'estimation de la fonction de coût duale à cette fonction montre alors la complémentarité entre les facteurs de la sous fonction. En particulier, nous montrons que la décroissance du coût d'usage du capital TIC aboutie à une augmentation de la demande du "facteur agrégé de productivité" et, par retour, des autres sous-facteurs constitués des actifs intangibles. Par cette méthode nous rejetons donc l'hypothèse de substituabilité unitaire entre les TIC et les actifs intangibles et nous montrons que l'innovation dans les TIC, aboutissant à une baisse du coût d'usage du capital TIC (évalué en termes d'efficacité), conduit à un accroissement des

rendements des autres investissements innovants. De cette façon nous montrons l'existence d'une complémentarité stratégique entre les producteurs et les utilisateurs de TIC au niveau macroéconomique et nous validons l'hypothèse que les technologies de l'information et de la communication génèrent des opportunités technologiques et donc la troisième propriété des TG.

**Conclusion** Le fait de définir l'unité d'une technologie générique comme l'ensemble des technologies (c'est-à-dire l'ensemble des applications des connaissances scientifiques) visant un but commun à tous les secteurs économiques, nous permet de définir les TIC comme une seule TG, dont le but est la traitement de l'information. Par ailleurs, le fait, d'une part, d'aborder l'ubiquité de la technologie non pas dans le sens d'une ubiquité des connaissances que la technologie applique mais par l'ubiquité des biens et services qui incorporent la technologie et, d'autre part, d'étudier les complémentarités d'innovation plutôt que des externalités de connaissance nous permet alors de valider l'approche des TIC comme une TG.

En outre, cette approche nous permet de déterminer la forme selon laquelle nous pouvons modéliser les TIC comme technologie générique dans un modèle macro-sectoriel. Cette modélisation devant intégrer, d'une part les externalités de connaissance inhérentes aux activités d'innovation et, d'autre part, les complémentarités stratégiques de recherche entre producteurs et utilisateurs de TIC par la complémentarité des TIC et des actifs intangibles en tant que facteurs de production.

Enfin, nous avons montré que, non seulement l'Europe a été moins performante dans l'innovation des TIC que les Etats Unis mais, aussi, que certains pays membres semblent avoir des difficultés à exploiter les opportunités technologiques créées par les TIC en investissant trop faiblement dans les actifs intangibles. Dans la perspective de la stratégie Europe 2020 et de ses composantes à la fois sur la R&D et sur le numérique, du fait de leur complémentarité, il est nécessaire de prendre en compte ces mécanismes dans l'évaluation des politiques. En particulier il semblerait nécessaire de coordonner les politiques d'adoption des TIC et les politiques de compétitivité basées sur la connaissance.





**Résumé:** Cette thèse a pour objet l'étude des Technologies de l'Information et de la Communication (TIC) en tant que Technologie Générique (TG) ainsi que leur rôle dans l'évolution de la productivité du travail aux Etats-Unis et en Europe durant les dernières décennies. La thèse est constituée de trois parties axées chacune sur l'une des trois propriétés fondamentales des TG: le progrès rapide de la technologie, l'ubiquité de la technologie et la capacité à créer des opportunités technologiques. La première partie décrit, dans un premier chapitre, l'innovation dans le domaine des TIC, en commençant par un bref historique de ces technologies, suivie d'une analyse des données contemporaines sur l'innovation dans ce domaine. Elle montre en particulier comment les Etats-Unis ont été, jusqu'à présent, plus performants que les pays Européens dans le développement des TIC. Dans un deuxième chapitre, cette première partie inventorie les difficultés de mesures induites par la vitesse et la nature du changement généré par ces technologies. La seconde partie de la thèse traite de la nature ubiquitaire des TIC. Elle décrit d'abord la diffusion des TIC au cours du temps à travers les pays et les secteurs économiques, puis, établit une revue de la littérature sur la contribution directe de la diffusion des TIC à la croissance de la productivité du travail aux US et en Europe. Le second chapitre de cette partie s'intéresse au comportement de demande de facteurs de production dans les secteurs producteurs de TIC ou intensifs en utilisation des TIC. Enfin, la troisième partie de la thèse se concentre sur la capacité des TIC à générer des opportunités d'innovation. Pour cela elle identifie d'abord la nature des innovations complémentaires et les efforts menant à ces innovations. Elle montre alors la nécessité d'améliorer la comptabilité nationale afin de prendre en compte ces efforts comme des investissements. Cette partie révèle ensuite que, dans les onze pays européens étudiés, le problème est particulièrement concentré sur quelques pays qui investissent peu en TIC et en actifs innovants et que ces deux types d'efforts sont complémentaires.

**Mots clefs:** Technologies de l'information et de la communication (TIC); Technologie générique (TG); Complémentarité technologique; Productivité du travail

**Abstract:** This thesis aims to study Information and Communication Technologies (ICT) as a General Purpose Technology (GPT) and their role in the labor productivity evolution in the United States and Europe during recent decades. This thesis is organized in three parts corresponding to the fundamental GPT features: the wide possibilities for development, the ubiquity of the technology and the ability to create large technological opportunities. The first part depicts, at first, the innovation in ICT, beginning with a short historical review of ICT inventions followed by the analysis of current data on innovation in this field. In particular, it shows how the US was better than the European countries in inventing ICT until now. Second, this first part makes an inventory of measurement difficulties due to the rate and the nature of the change created by such technologies. The second part of the thesis deals with the ubiquitous nature of ICT. It first describes the ICT diffusion across countries and industries and reviews the economic literature on the direct contribution of ICT on labor productivity growth in the US and Europe. The next chapter studies the factor demand's behaviour in sectors that are either ICT producers or ICT intensive users. The third part focuses on the ICT ability to create opportunities for complementary innovations. Firstly, it identifies the nature of ICT complementary innovations and the corresponding efforts. It shows, then, that national accounts must be improved in order to take these efforts into account as investments. Secondly, this part shows that, among the eleven European countries studied, the problem is highly concentrated in a few countries that invest less both in ICT and in innovative assets and that these two types of effort are complementary.

**Keywords:** Information and communication technologies (ICT); General purpose technology (GPT); Technological complementarity; Labor productivity