European Labor Markets

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European Labor Markets.

A Macroeconomic Vision.

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European Labor Markets:
A Macroeconomic Vision

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Contents

List of Figures

List of Tables

Résumé en Français

Plusieurs forces structurelles ont modifié l'économie et plus spécifiquement les marchés du travail au niveau mondial ces dernières décennies. D'abord, le commerce international a fortement augmenté, avec une croissance des échanges de biens finaux et la délocalisation de certaines tâches de production vers des pays à bas coûts. Ensuite, avec les progrès technologiques notamment en informatique, les robots ont remplacé les travailleurs sur un nombre croissant de tâches mais ont aussi amené à la création de nouveaux emplois. Enfin, les crises sont devenues beaucoup plus globales, touchant l'ensemble des pays du monde. C'est notamment le cas de la crise économique et financière qui a débuté en 2007 ou de la crise du COVID-19.

Cette thèse a pour but d'étudier certaines conséquences que ces forces structurelles ont eu pour les pays européens et de possibles solutions pour y faire face. L'Europe a plusieurs spécificités qui en fait une zone d'étude de grand intérêt. Ce continent a fortement changé ces dernières décennies du fait de plusieurs décisions politiques aux larges conséquences économiques. La chute de l'Union Soviétique a mis fin au communisme en Europe de l'Est et a sacré le capitalisme comme système dominant sur l'ensemble du continent. L'Union Européenne a amené la paix sur le continent ainsi qu'une liberté de mouvements des biens et des capitaux dans vingt-sept pays. Finalement, les dix-neuf pays de la zone Euro utilisent maintenant une monnaie unique.

Néanmoins, les pays de la zone Euro sont extrêmement hétérogènes. Les langues et cultures sont différentes d'un pays à l'autre. D'un point de vue économique, ces pays ont également un PIB par habitant, un taux de chômage ou des législations concernant le fonctionnement de l'économie différents. Cependant, ces pays ont décidé de perdre leur souveraineté monétaire pour la laisser aux mains de la Banque Centrale Européenne. Or, il est extrêmement difficile pour une Banque Centrale de mettre en œuvre une politique monétaire qui convienne en même temps à des membres aussi hétérogènes. Par ailleurs, il y a très peu de mobilité des travailleurs et de transferts fiscaux entre les pays de la zone Euro. En conséquence, la zone Euro a eu beaucoup de mal à faire face à la crise économique et financière qui a commencé en 2007. En effet, cette crise a touché de manière asymétrique les différents pays de la zone Euro qui n'ont pu compter ni sur une politique monétaire personnalisée ni sur une véritable coopération à base de transferts fiscaux. De ce fait, diminuer les différences entre les pays de la zone Euro pourrait améliorer la résilience de la zone aux différents chocs économiques négatifs.

Pour ces raisons, dans un premier chapitre, j'analyse les conséquences en terme de bien-être d'une convergence des législations régissant les marchés du travail dans la zone Euro. Pour se faire, j'utilise un modèle stochastique d'équilibre général à deux pays (un flexible et un rigide) appartenant à une union monétaire. Ces deux pays ont des coûts de licenciements, une structure syndicale et un niveau d'assurance chômage différents. Je fais converger ces différents éléments législatifs entre les deux pays pour analyser les conséquences sur l'emploi, la consommation, le revenu, les salaires et le bien-être.

Je trouve que le pays avec un marché du travail rigide gagne à converger avec le pays flexible dans la plupart des cas étudiés, alors que pour le pays flexible, une telle convergence a souvent des conséquences négatives. Pour les deux pays, les conséquences sont meilleures si la convergence s'effectue vers une législation plus flexible du marché du travail. L'union monétaire gagne en terme de consommation, revenu, emploi et salaire pour la majorité des cas étudiés. Ces résultats sont valides qu'il s'agisse d'une étude statique entre états stationnaires, ou dynamique avec la transition du monde actuel hétérogène vers un monde homogène. Ainsi, une telle convergence peut avoir de larges conséquences positives si elle est mise en place avec soin.

Deuxièmement, les tâches routinières peuvent facilement être effectués par des travailleurs dans d'autres pays ou par des robots. De ce fait, la délocalisation et l'automatisation ont modifié structurellement les marchés du travail en Europe. Elles sont souvent citées comme causes de la polarisation du marché de l'emploi dans les pays développés. Cette polarisation signifie que les emplois routiniers au centre du spectre salarial ont diminué au profit à la fois des emplois manuels non-routiniers moins bien payés et des emplois abstraits nécessitant de plus fortes qualifications et mieux payés.

L'objectif du deuxième chapitre est d'étudier les conséquences de l'automatisation et des délocalisations sur la distribution de l'emploi en Europe de l'Ouest entre 2000 et 2016. Pour cela, j'utilise un modèle d'équilibre général dans lequel les travailleurs routiniers d'Europe de l'Ouest peuvent être remplacés par ceux d'Europe de l'Est ou d'Asie et où des robots sont complémentaires aux travailleurs abstraits mais substituts des travailleurs routiniers. J'utilise ensuite les données précises de baisse des prix des robots et du coût du commerce international pour comprendre le rôle de ces deux facteurs.

Mon modèle arrive à reproduire précisément l'évolution de la quantité des tâches délocalisées ainsi que de la polarisation du marché du travail en Europe de l'Ouest. Je trouve que l'automatisation est le facteur principal expliquant cette polarisation. C'est notamment le seul facteur contribuant à l'augmentation du nombre de travailleurs abstraits. La délocalisation a un plus faible impact alors que le commerce de biens finaux n'a aucun effet. Finalement, la polarisation du marché du travail implique une augmentation du revenu et de la consommation sur le long terme malgré une légère baisse sur le court terme.

Troisièmement, l'adoption de machines a stimulé le développement économique par le passé. Mais, l'accélération croissante de l'automatisation notamment due au développement de l'intelligence artificielle a poussé plusieurs auteurs à remettre en question la relation positive entre progrès technique et amélioration des conditions de vie. L'idée de taxer les robots pour limiter cette automatisation a donc récemment fait son entrée dans le débat public.

Pour contribuer à ce débat, dans un troisième chapitre, j'étudie les conséquences de taxer ou subventionner les robots dans une petite économie ouverte. J'utilise une version simplifiée du modèle du chapitre précédent appliquée à l'Espagne. Ce pays est particulièrement intéressant car il a connu de fortes automatisation et polarisation du marché du travail ces dernières années.

Je trouve que l'augmentation de l'automatisation améliore le niveau de bien-être et qu'il est donc optimal de subventionner l'investissement dans les robots. Cela vient principalement du fait que l'automatisation augmente la productivité des travailleurs. Cependant, l'effet de la subvention peut être négatif sur le court terme puisque cela accélère la baisse du nombre de travailleurs routiniers. Enfin, les gains sont faibles comme le poids des revenus provenant des robots reste bien plus faible que l'ensemble des salaires perçus par les travailleurs.

General Introduction

Technical progress has been modifying the economy and the society of Western European countries at least since the Industrial Revolution. Until the end of the 18th century, the overwhelming majority of the individuals worked in the agricultural sector. In Malthusian societies, labor was the only factor of production while population and economic growth were null (see Malthus (1872)). With the Industrial Revolution, the number of machines exploded, the industrial sector strongly rose and the agricultural production increased despite requiring less workers. Technical progress has caused many more structural changes up to today. With the inception of the electricity, an even larger part of the economy was transformed. Similarly, the improvement of boats, the creation of planes – associated with different agreements to diminish trade barriers – led to the rise of international trade. This allowed firms and countries that were more productive thanks to the use of machine to find a new demand and increase their production, pushing firms to automate even more (see Mokyr, Vickers, and Ziebarth (2015)). Logically, those transformative changes have also had a large impact on labor markets during the last two centuries. Old jobs have seen their content being modified and tasks have been supplied in a new way or have even been destroyed while new jobs have been created. For instance, in the 19th century, new skilled workers were required to create textile machines that were operated by low-skill individuals while the skilled manual textile workers disappeared.

The effect of technical progress on labor market structures is probably even more important since the beginning of the 21st century. With the rise of the Internet, the progress in electronics, programming and artificial intelligence, more and more tasks can be supplied by machines and automation could proceed at a higher pace in the close future. Moreover, it has become easier for firms to produce in different places. They can now divide the production process into several steps that can be supplied in different countries depending on costs and available skills. This process, called offshoring, puts workers in competition globally. Furthermore, technical progress and political decisions have made movements of individuals, goods and capital easier, cheaper and quicker between the different countries. While this has brought large benefits, it has also caused crises to become more global through interconnection, which has amplified their consequences. For instance, the Great Recession and the recent Covid-19 crisis have hurt all the countries of the World – although asymmetrically according to local circumstances.

Developed countries are the most advanced countries in terms of technology, they have the highest labor costs and political decisions have made them largely open to trade and finance. As such, they are the most likely to be transformed by the structural forces of automation and offshoring. Among them, European countries are of great interest. While the European continent was divided in two during the Cold War, with the fall of the USSR, communism has disappeared in Eastern Europe. As such, capitalism is the only economic system of the continent. Besides, the European Economic Community that became the European Union has been extended to Central and Eastern European countries. This union has preserved peace between European countries and has facilitated economic activity by allowing free movements of goods and capital among its members. A stronger cooperation has even been implemented with the creation of the European monetary system. Nineteen countries now have the same currency and monetary authority. However, despite those different political decisions towards an increased cooperation, a strong economic heterogeneity coming from the historical divisions remains between those countries. This means that structural forces bring specific challenges in Europe.

This PhD thesis looks at some of the consequences of those structural forces for European countries since the beginning of the 21st century and the possible solutions to deal with those forces considering European specific features. To do so, I use general equilibrium models following the new open-economy macroeconomics tradition (see Backus, Kehoe, and Kydland (1992) or Obstfeld and Rogoff (1995)). This theoretical framework is at the core of current macroeconomic studies. Contrarily to older models, general equilibrium models are microfounded. They depend on the behavior of households and firms, notably their intertemporal choices. In the following chapters, I use those models to study past events, the present economy or possible future policy changes. Indeed, this theoretical framework allows to conduct counterfactual analyses to understand the precise effects of each studied factor on the main macroeconomic aggregates or the welfare of the agents. We can also study the impacts of the same stochastic shocks on countries with different characteristics or the consequences of implementing a new policy both in the short term and in the long term.

General equilibrium models also have the advantage to allow us to easily add different equation blocks to the baseline framework depending on the precise focus of the study. For example, as the first chapter studies a monetary union, I add price rigidities *à la* Rotemberg (1982) to look at the effect of the common monetary policy. Similarly, as I am particularly concerned with labor-market variables, I add the search and matching framework to the model in the tradition of Pissarides (1979), Mortensen (1982) and Diamond (1982) to understand unemployment variations by including firing costs, bargaining power or unemployment insurance benefits. But, in the following chapters, I focus on the distribution of employment (and not unemployment) in the medium run, looking at structural change. As such, search and matching frictions or sticky prices are not considered.

A few hypothesis I make in the following models need to be detailed. First, although households may display heterogeneous characteristics, I consider that all individuals of a country belong to a single family and pool their income as in Merz (1995). As such, each of them choose the same level of consumption and investment. This modeling choice prevents from studying inequalities or distributional issues. However, it insures that the model remains tractable and facilitates the grasp of the underlying dynamics. Second, in Chapter 2, I consider that a trade cost is paid when international trade takes place. This trade cost includes all types of costs paid when exchanging with another countries: tariffs but also transportation or administrative costs for example. As tariffs in Europe have been low during the last two decades, I consider that those costs are wasteful frictions and not rebated to the foreign government or households. Those trade costs are indirectly added in Chapter 1 and 3 through the presence of a bias in favor of home tradable goods. Besides, when looking at offshoring in Chapters 2 and 3, I add a supplementary cost that changes according to the type of task that is offshored. A high offshoring cost means that the language and the culture of the firm must be known or that it is important to know the firm's clients for example. This allows to explain why some tasks are offshored and others are not without requiring differences in terms of labor productivity between workers of similar skills.

This thesis is divided in three chapters. First, I study the consequences of implementing a convergence of labor-market legislations in the Eurozone. Second, I look at the causes of labor-market polarization in Western Europe. Finally, I examine the welfare impact of implementing a robot subsidy in Spain.

0.1 Heterogeneity and Convergence of Labor Markets

Countries of the Euro Area have different cultures, languages and forms of governments but one common monetary authority and currency. Those countries have abandoned their monetary sovereignty without undertaking any real measure of homogenization of their economies. Furthermore, labor mobility and fiscal transfers between the countries are extremely limited. This lack of risk-sharing mechanisms to lessen the consequences of asymmetric shocks is a danger in a monetary union of heterogeneous countries. This danger was particularly visible after the Great Recession that hit European countries asymmetrically. In 2016, the unemployment rate was still a third higher than in 2007 for the Euro Area. It was even the second highest among OECD countries. Finding ways to decrease the heterogeneity of the economies of the Euro Area is thus of great importance considering the globalization of crises.

One possibility is to modify the legislations of labor markets to make them more homogeneous among members of the Euro Area. Indeed, European labor markets display strong differences, notably in terms of unemployment insurance schemes and labor-market transition probabilities. For example, the unemployment benefit replacement rate goes from 20% in Malta to 92% in Portugal while the duration period ranges from 28 weeks in Slovenia to an unlimited period in Belgium (see Esser et al. (2013)). Besides, the level of flexibility of the labor markets is very heterogeneous from a country to another. In Germany, the Netherlands or Ireland – countries considered as flexible – firms can modify the size of their workforce in a quicker and more efficient way. Temporary workers have rather similar rights as permanent workers and the transition probabilities from temporary to permanent jobs are higher (see Nardo and Rossetti (2013)). Those differences are usually considered as the main reasons explaining the divergences in terms of economic performances between European countries. The indicator often used to demonstrate this argument is the unemployment rate. Data clearly indicate that countries with a high level of labor-market flexibility are more likely to have a low unemployment level while countries with a low level of flexibility as Spain or Greece display a high unemployment level.

Many authors have worked on the negative consequences of a low level of labor-market flexibility. Blanchard and Wolfers (2000) and Ljunqvist and Sargent (2008) show that this relatively low flexibility is the key factor to explain that the unemployment levels are higher in Europe than in the United States since the late 1970s. Blanchard and Giavazzi (2003) and Gomes et al. (2013) look at which employment protection legislation should be modified to diminish the unemployment level in Europe. Meanwhile, Cacciatore et al. (2016) or Eggertsson, Ferrero, and Raffo (2014) are interested in the timing of such reforms. But those papers only look at the consequences of an improvement of labor-market flexibility in a homogeneous country or region while the heterogeneity of the labor markets of the Eurozone are a main concern. A few papers started to study the negative consequences, especially for unemployment, of this heterogeneity (see Dellas and Tavlas (2005), Andersen and Seneca (2010), Abbritti and Mueller (2013) or Kontogiannis (2015)). But they are not interested in structural reforms diminishing both the rigidity and the heterogeneity of European labor markets.

Only two papers look at the outcomes of such structural reforms: Dao (2013) and Poilly and Sahuc (2013). Using multiple-country DSGE models, both papers find positive consequences for both countries of increasing the flexibility of the most rigid country to make it resemble the flexible one. Nevertheless, some important elements are absent in their modeling frameworks. As they consider a model with complete financial markets, they cannot fully consider the potential wealth transfers within the monetary union. Further, firing costs are missing from their models while it is a crucial element of labor-market legislations. Finally, they are only interested in the homogenization of labor markets towards the most flexible country. Therefore, a more complete framework is needed.

In this respect, the first chapter of the thesis aims at understanding the welfare consequences of a homogenization of labor markets in the Euro Area with a two-country monetary-union model. I include search and matching frictions in the tradition of Mortensen (1982) Pissarides (1979) and Diamond (1982) and add firing costs as in Zanetti (2011). Consumption and investment goods are internationally tradable but a home bias exists. Prices are sticky as in Rotemberg (1982). Countries are structurally heterogeneous following actual data:

the Home country represents flexible countries of the Euro Area while the Foreign country represents rigid countries. Especially, the net insurance replacement rate, the firing costs and the bargaining power of workers are lower in the flexible country. When fed with asymmetric productivity shocks, the model matches well the business cycle moments. First, I look at the consequences of making the parameters converge, one at a time, towards the flexibility level of the Home country to disentangle the impacts of each parameter and then study the effects of making them converge at the same time. Then, I look at the welfare consequences of a convergence of all three parameters at different levels of labor-market flexibility. I conduct two exercises. First, I compare the welfare levels at the steady-state between the model with heterogeneous labor markets and the one with homogeneous labor markets. I compute both stabilization and structural welfare gains. Second, I study the welfare changes during the whole transition path from heterogeneity to homogeneity, looking at short and long-term changes.

I find that each parameter has different consequences on unemployment, wages, consumption and output when brought to its value in the flexible country. First, making the firing costs converge leads to an increase of wages which causes a rise of unemployment. However, the wage increase is large enough to bring a rise of consumption and output. Second, decreasing the unemployment benefits to their level in the flexible country leads to a small diminution of wages. However, unemployment decreases, leading to an aggregate increase of consumption and output. Finally, the convergence of the bargaining power of workers has the strongest positive effect. It causes an increase of wages, consumption, output and a decrease of unemployment.

A joint convergence of the three parameters to their value in the Home (flexible) country leads to a mix of the previous results. On impact, the effect of the decrease of the firing costs dominates, causing an increase of wages as low-productivity workers become too costly and are fired. As such, unemployment also increases but consumption still rises. After a few periods, the positive effects of the decrease of both the unemployment benefits and the bargaining power of workers prevails. The wage decreases as the outside option diminishes. As such, the price of the good of the Foreign country diminishes, causing a rise of its demand and a need for more hires, leading to a lower unemployment level. Later, wages also increase as the labor market becomes tighter. Thus, Foreign output and consumption increase by respectively 7% and 3% while unemployment drops by 25%. For the Home country, the effects of the convergence are negative in the short term as individuals substitute the Home good for the Foreign one. However, after some time, the income effect dominates. As the price of the Foreign good decreases, the purchasing power of the households increases in both countries. Therefore, the reform has a positive effect in the long run even for the Home country: output, consumption and wages increase while unemployment falls.

Second, the steady-state to steady-state welfare comparison indicates structural gains for the rigid country and losses for the flexible country for most convergence scenarios I study. Further, the after-convergence flexibility level is of paramount importance: the higher the flexibility level, the higher the gains – or the lower the losses. Indeed, a convergence towards a higher flexibility level decreases unemployment and increases consumption, causing a higher level of welfare. Nevertheless, the positive spillover effect from the Foreign country is strong enough to lead to positive welfare changes for the Home country for high after-convergence flexibility levels. Similarly, when the convergence is made at a low level of flexibility, the negative spillover effect from the Home country causes a decrease of structural welfare in the Foreign country. The Monetary Union experiences welfare gains for a large range of after-convergence flexibility levels. Structural gains can be quite high, up to 1.6%, 0.4% and 1.1% of permanent consumption for the Home country, the Foreign country and the Monetary Union as a whole. Stabilization welfare gains follow the same pattern although with a lower magnitude. The Foreign country wins while the Home country loses in most cases and the higher the after-convergence flexibility level, the better the welfare outcome. With a high level of flexibility, the movements in employment and unemployment are smoother. This causes a lower volatility of consumption and therefore it brings stabilization welfare gains. Further, a greater homogeneity inside the monetary union improves the response of the monetary authority, making monetary policy better fitted to local conditions. As such, stabilization gains occur for a larger range of calibrations than structural gains. Gains are up to 0.23% and 0.07% of permanent per-capita consumption respectively for the Home and Foreign countries.

Finally, looking at the transition path does not really modify the previous results from a long-term perspective. The Foreign country experiences welfare gains and the Home country welfare losses for most calibrations. Again, the higher the after-convergence flexibility level, the higher the welfare gains. However, the results are somewhat different in the short run. The negative spillover effect coming from the rigidification of the labor market of the Home country takes time to materialize. As such, in the short run, the Foreign country experiences welfare gains for any after-convergence flexibility level I study. This also means that, on the long term, the Foreign country gains in terms of welfare for a bigger range of calibrations. Similarly, the Home country suffers from welfare losses for any calibration in the short term as the positive spillover effect coming from the Foreign country is not perceived during the first few periods. Thus, an homogenization of labor-market legislations can be extremely positive if carefully implemented.

0.2 Dynamics of the occupational distribution of employment

Technical progress has caused a strong rise of automation and offshoring since the beginning of the 21st century. Machines have replaced workers for an increasing number of tasks while firms have divided their production process between different countries. Arguably, these forces have only had short-term effect on the total demand for labor as they have led to the creation of new jobs. However, they have transformed the organization of labor and, more importantly, have caused structural modifications on the distribution of employment. The main structural dynamic of the occupational distribution of employment that has occurred in the United States and Europe during the last decades is called labor-market polarization. This notion means that the number of routine tasks performed by middle-skill workers are strongly diminishing while the numbers of abstract tasks supplied by high-skill workers and manual tasks performed by low-skill workers are increasing.

The role of automation in this labor-market polarization has been easily explained through theoretical models (see Autor, Levy, and Murnane (2003), Acemoglu and Autor (2011), Autor and Dorn (2013), Lee and Shin (2017) or Bárány and Siegel (2018)). Routine tasks are the easiest tasks to automate. As such, some routine workers are replaced by machines and are forced to supply manual tasks for a lower wage or have to train to become high-skill workers and perform abstract tasks. This relation between automation and labor polarization has been supported by empirical studies looking at several European countries (see Goos, Manning, and Salomons (2014) and Michaels, Natraj, and Van Reenen (2014)), or a single country (see Senftleben-König, Wielandt, et al. (2014) and Dauth et al. (2017) for Germany or Gaggl and Wright (2017) for the United Kingdom).

Similarly, many authors have argued that international trade through an increase of offshoring has contributed to the polarization of employment. Indeed, routine tasks can usually be supplied from distance and rarely require specific knowledge about the producing firm or the clients of the produced good. As such, with the decrease of trade costs, more and more firms from developed countries have started to offshore those tasks to countries with a lower labor cost. This effect has been explained through theoretical models mainly for U.S. firms (see Feenstra and Hanson (1997), Grossman and Rossi-Hansberg (2008), Ottaviano, Peri, and Wright (2013) or Eeckhout and Jovanovic (2012)) and documented empirically both for U.S. and European firms (see Biscourp and Kramarz (2007), Mion and Zhu (2013) or Baumgarten, Geishecker, and Görg (2013)). A few recent theoretical papers even look at the role of both automation and offshoring on labor-market polarization (see Jung and

Mercenier (2014), Cavenaile (2018) and Mandelman and Zlate (2021)). However, they only focus on the United States. As such, a new framework specially designed and parametrized for Europe is needed.

In this regard, the second chapter aims at understanding the relative roles of automation and international trade on the dynamics of the employment distribution in Western Europe between 2000 and 2016. This period is of particular interest as both automation and trade have largely increased. First, new forms of automation have appeared with the creation of the internet. Second, trade has been boosted by the entry of China in the World Trade Organization in 2001 and the entry of Central and Eastern European countries in the European Union in 2004 and 2007. Moreover, a strong labor-market polarization occurred during the period. Abstract and manual occupations rose, respectively by 4.3 and 2.3 percentage points of the non-agricultural labor force while routine occupations fell by 6.6 percentage points.

To examine the roles of automation and trade, I build a general equilibrium model with three regions (Western Europe, Eastern Europe and South Asia) and three types of workers. Low-skill individuals supply manual tasks for the production of a non-tradable good or train to become middle or high-skill workers. Middle-skill workers providing routine tasks and high-skill workers supplying abstract tasks produce an internationally tradable good using Information and Communication Technology (ICT) capital but may lose their skills at any period. ICT capital is a relative complement with abstract labor but a relative substitute with routine labor. Furthermore, Western European firms can offshore routine tasks to Central and Eastern Europe or South Asia. The amount of offshored labor depends on a trade cost and an "offshorability" cost that is task-dependent. The steady state is carefully calibrated to match the characteristics of the three regions in 2000. Then, I subject the model to actual yearly exogenous processes for ICT-capital prices and trade costs. The model precisely depicts the increase of offshoring and the polarization of employment. From this starting point, I conduct a counterfactual analysis, studying the role of each of the driving forces in explaining the dynamics of employment distribution. Finally, I look at the welfare consequences for Western Europe of the decrease of ICT-capital prices and trade costs during the period.

First, the suitability of my modeling framework is shown by its ability to depicts almost perfectly the dynamics of the amount of labor offshored to Central and Eastern Europe and Asia. Then, it precisely reproduces the labor-market polarization. The non-agricultural routine labor share drops from 34.4% to 28.4% in the model while it falls from 34.4% to 27.8% in the data. The abstract labor share rises from 38.5% to 42.2% in the model while it reaches 42.8% in the data. Finally, the manual labor share goes from 27.1% to 29.4% in the model and the data. The decrease of both trade costs and ICT-capital prices easily explain these dynamics. The decrease of trade costs leads firms to offshore more tasks to the other two regions as the cost of offshoring diminishes. As such, less domestic routine workers are needed, leading to an increase of manual labor. The decrease of ICT-capital prices pushes firms to increase their investment in machines. As ICT capital is a relative substitute with routine labor, routine workers are not replaced and manual labor increases. Further, automation leads to an up-skilling of the population, meaning that more individuals train to become high-skill workers. Indeed, as ICT capital is a relative complement with abstract labor, its increases causes a rise of the need for high-skill workers.

Second, making the model run with only one driving force at a time, I find that the increase of automation is the key factor explaining the dynamics of employment over the period. As planned, it causes the totality of the increase of the abstract labor share. But, it also explains 82% of the fall of the routine labor share and 57% of the rise of the manual labor share. The rest is explained by the increase of offshoring. The effect of international trade on final goods is almost nonexistent as its amount is extremely low.

Finally, conducting a cumulative welfare analysis, I find that Western Europe increased its aggregate welfare between 2000 and 2016 thanks to the fall of trade costs and ICT-capital prices. Per-capita consumption increased by 2.5%. Automation is the main reason behind this increase as it is the key factor of labor-market polarization. Nevertheless, welfare changes are negative in the short run. Indeed, short-term consumption and investment decrease to pay for a rise of high-skill training. But, after a few periods, consumption increases as the country has a bigger share of high-skill workers who earn a higher wage. As utility is discounted over time, cumulative welfare only becomes positive in 2011. The decrease of trade costs has a smaller but always positive effect on welfare as it leads to a fall of the prices of the different tradable goods.

0.3 ICT capital, optimal taxation and welfare

As using capital structurally modifies the labor market, people have opposed the introduction of new machines for more than two centuries. For instance, the Luddite movement – consisting of high-skilled textile workers – strongly opposed the development of large factories with textile machines operated by low-skill workers at the beginning of the 19th century in England. However, high-skill workers are required to build those machines and make them function properly. Besides, adopting them allows to improve the production process and decrease the price of goods. As such, technical progress has improved economic conditions in the past (Mokyr, Vickers, and Ziebarth (2015)). Nevertheless, new debates about the socially optimal level of automation have arisen with the rise of Artificial Intelligence. Indeed, it could lead to a modification of task content and an automation at an accelerating rate (Brynjolfsson and McAfee (2014), Ford (2015), Frey and Osborne (2017)). As such, it might not be possible to create enough new jobs to compensate those job losses. This has led several authors to ask for a limitation of the amount of robots. One way to control the level of automation for policymaker is to tax – or subsidize – the returns on ICT capital. Implementing robot taxation would be socially optimal if automation destroys jobs without replacing them while implementing a robot subsidy would increase welfare if automation keeps having a positive economic impact as in the past.

Several scholars (*e.g.* Abbott and Bogenschneider (2018), Mazur (2018), Hemel (2020)) have developed practical and legal arguments in favor or against robot taxation in the last few years, especially after the debates on this question in the European parliament in 2017. But, economic theoretical arguments about optimal taxation date back to Ramsey (1927). Using the method of Ramsey, it was shown that the absence of capital taxation is optimal in simple models (see Judd (1985) and Chamley (1986)). However, with the presence of different types of workers (Jones, Manuelli, and Rossi (1997)) and especially when adding capital-skill complementarity (Angelopoulos, Asimakopoulos, and Malley (2015), Acemoglu and Restrepo (2020)), it can be optimal to tax or subsidize capital in the Ramsey framework. Moreover, other authors use the Mirrleesean approach in a model with heterogeneous households. They find that a rather small positive robot tax increases welfare for redistributive reasons (see Slavik and Yazici (2014), Guerreiro, Rebelo, and Teles (2017), Costinot and Werning (2018), Thuemmel (2018)). Other types of models have been developed by Chu et al. (2018), Gasteiger and Prettner (2017) or Zhang (2019) to contribute to the debate on the question.

However, those different models either do not imply a precise quantitative exercise or are calibrated to the United State economy, and mostly focus on redistributive concerns. Only Humlum (2019) looks at a model specially calibrated to an open European economy (Denmark). He finds that a 30% robot tax diminishes aggregate welfare but increases the welfare of older workers in the manufacture sector. However, he does not look at the optimal level of robot taxation and uses a more empirical approach.

This third chapter complements the existing literature by developing a thorough study of robot taxation/subsidy in a general equilibrium model applied to Spain. I use a simplified version of the model of Maillard (2021) adapted for the present issue. A small open economy is composed of a large family with three types of workers. High and middle-skill workers supplying respectively abstract and routine tasks produce a tradable good with ICT capital. Low-skill workers produce a non-tradable good by supplying manual labor. Workers become middle or high-skilled through training but may randomly lose their skills at each period. As usual in the literature, I consider that ICT capital is a relative complement with abstract labor but a relative substitute with routine labor. Routine labor can also be offshored to a sub-region of the Rest of the World representing Central and Eastern Europe and Asian developing countries. The level of offshoring depends on a trade cost and an "offshorability" cost that depends on the task. A government finances its spending using taxes on ICT capital and labor. The small open economy is parametrized to match key variables of the Spanish economy in 2016 while the economy of the Rest of the World is determined exogenously. Spain is of particular interest as it has faced a strong labor-market polarization and a large increase of automation caused by the drop of the price of ICT capital for the last two decades. First I compute the optimal Ramsey policy using robot taxation as instrument. I find that a very large robot subsidy is welfare maximizing. Second, I consider the impact of implementing a more moderate subsidy. Third, I analyze the transition process of this subsidy when the downward trend of ICT-capital prices is taken into account.

By computing the Ramsey plan, I find that an unrealistic subsidy, largely superior to one is optimal. This result has two main causes. First, capital and labor incomes are equally shared among the members of the large family. Second, the size of capital income is much lower than the one of labor. As such, it is welfare maximizing to have an almost null net rate of return on capital and pay the labor tax of only 2.4% that compensates the robot subsidy. This subsidy decreases the cost of ICT capital. The resulting increase of automation causes the usual labor-market polarization: abstract and manual labor shares increase while the routine share decreases. Besides, it leads to a decrease in the price of the tradable good which causes an increase in demand for the good at home and abroad and requires an increase of productivity. Therefore, abstract and routine wages rise. The manual wage also slightly increases as tradable and non-tradable goods are complements.

As such, output and consumption increase. Finally, the labor tax has a small negative effect on the labor supply. As consumption rises and the disutility from labor decreases, welfare logically increases. However, welfare gains are quite small.

As the optimal subsidy level is too high to be implemented, I look at the welfare consequences of implementing a more moderate 50% robot subsidy. Variables logically vary similarly in this case but at a lower magnitude. Welfare gains are about a third as high as for the optimal Ramsey plan. The labor-market polarization still occurs while wages, output and consumption increase. Those results are consistent with the results in Humlum (2019) and with the aggregate benefits of automation found by Koch, Manuylov, and Smolka (2021) for Spain or Aghion et al. (2020) for France.

Finally, as ICT-capital price has strongly decreased in Spain since the beginning of the century, I take it into account when examining the transition process of implementing a robot subsidy. I find that a 5% yearly ICT-capital price decrease rises welfare by 1.1% of permanent consumption over a fifteen year period. Welfare variations are always positive during the period but it diminishes for a few years after the initial increase. The family responds to the first unexpected ICT-capital price decrease by increasing consumption and abstract labor training but diminishing investment. This increases welfare for the first period but has negative consequences for the following periods. As investment decreased, ICT-capital gains and the number of abstract workers also diminish, causing a decrease of cumulative welfare. Only after a few years, the exogenous decrease of ICT-capital price lead to the expected increase of wages, output, consumption and cumulative welfare. Adding the 50% robot subsidy to this path of ICT-capital price does not strongly modifies the dynamics. It leads to welfare gains of about 1.35% of consumption over the period studied but induces lower gains in the short run. Indeed, it amplifies the initial replacement of routine labor by less paid manual labor. Nevertheless, the lower ICT-capital price level resulting from the subsidy leads to a higher increase of wages, output, consumption and thus welfare after a few periods. All the main results of this chapter are robust to a large variety of parameter values and model specifications such as inelastic labor supply, positive government spending, complete international financial markets, sectoral mobility costs or unemployment.

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Chapter 1

Heterogeneity, Rigidity and Convergence of Labor Markets in the Euro Area

Abstract

This chapter investigates the welfare consequences of labor-market convergence reforms for a large range of calibrations in a two-country monetary-union DSGE model with search and matching frictions. The model features trade in consumption and investment goods, price stickiness, firing costs and is calibrated to reflect the structural asymmetries of flexible and rigid countries of the Euro Area in terms of size and labor-market variables. Across steady states, convergence brings welfare gains for the rigid country and welfare losses for the flexible country in most situations studied. The higher the flexibility induced by the convergence, the higher the welfare gains. Taking into account the transition path does not strongly modify the insights of the steady-state analysis. However, the number of situations in which both countries experience long-term welfare gains is higher than in the steady-state analysis. In the short run, the rigid country experiences welfare gains and the flexible country welfare losses whatever the situation. As such, I conclude that a convergence of the labor markets can lead to substantial welfare gains in a monetary union, especially if the implementation is carefully designed.

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1.1 Introduction

The Eurozone is a monetary union of nineteen countries with heterogeneous structural characteristics. Unlike optimal currency areas,[1] labor mobility is extremely limited and fiscal transfers are almost absent. The loss of monetary sovereignty by the countries of the Economic and Monetary Union (EMU) combined with the lack of cooperation and risk-sharing mechanisms to deal with asymmetric shocks has led the EMU to have great difficulties facing the Great Recession. Relying on several economic indicators, the Euro Area appeared in worse shape ten years after the crisis than it was just before. For instance, as indicated by OECD data, the unemployment rate in the Euro Area was at 10% of the active population in 2016, compared to 7.5% in 2007. Besides, only Turkey among OECD countries had a higher unemployment rate than the Euro Area in 2016.[2] Finding means to cope efficiently with asymmetric shocks, or shocks that spread asymmetrically is thus of great importance for the Euro Area.

In this respect, I investigate the welfare consequences of labor-market convergence reforms in a two-country monetary union model with search and matching frictions, where countries are asymmetric in terms of labor-market variables. Eurozone countries display important labor-market differences, especially in terms of labor-market transition probabilities and unemployment insurance schemes. For instance, most countries have a net unemployment benefit replacement rate between 50% and 70% but there are huge differences between Malta, that has a net replacement rate of 20%, and Portugal, where the replacement rate is at 92%. Moreover, the duration period of eligibility ranges from 28 weeks in Slovenia to an unlimited period in Belgium (Esser et al. (2013)). Countries in the Euro Area can also be divided according to the flexibility of their labor markets, that results from legislative choices. In flexible countries as Germany, the Netherlands or Ireland, firms make quicker and more efficient adjustments of their workforces. Employees have more flexible working

[1] See Mundell (1961) or McKinnon (1963).
[2] The comparison with other OECD countries is presented in Appendix 1.7.1.

time arrangements, the legislation protecting regular workers is close to the one protecting temporary workers and voluntary part-time work is higher. Moreover, overtime hours are more often observable and transition from temporary to permanent employment is higher (see Nardo and Rossetti (2013)). Differences in terms of labor-market flexibility is considered by many authors as the main reason explaining the strong heterogeneity in terms of unemployment rate in the Eurozone, lower flexibility leading to higher unemployment levels. Data from the Eurostat seem to confirm this analysis. Flexible countries as Germany, Austria or the Netherlands experienced low unemployment rates in 2016 while rigid countries as Greece or Spain featured high unemployment rates.[3]

My two-country DSGE model features sticky prices, trade in consumption and investment goods, and home bias as in Pappa and Vassilatos (2007). Labor markets are frictional in the tradition of Pissarides (1979), Mortensen (1982) and Diamond (1982). Firing costs are added as in Zanetti (2011). The Home country is meant to gather the flexible countries of the EMU while the Foreign country resembles the rigid countries.[4] I carefully calibrate the model using Euro Area data. Countries are asymmetric in size, home bias and most labor-market variables. In particular, in the steady state, the flexible country has a lower unemployment rate and a lower net unemployment benefit replacement rate, as in the data. Fed with asymmetric stochastic productivity shocks, the model matches business cycle moments satisfactorily. I then use the model to investigate the effects of labor-market convergence reforms: firing costs, UI benefits and the bargaining power of workers become identical in both countries at various levels of labor-market flexibility while the steady-state value of other variables adjusts endogenously. First, I look at the consequences on major variables of making each parameter converge one at a time, to better disentangle the different effects at play. Second, I look at a joint convergence of the three parameters. Two welfare comparison exercises are conducted: a steady-state to steady-state welfare

[3]The precise unemployment rate of each country of the Eurozone is presented in Appendix 1.7.1.

[4]From now on, I will use indifferently Home/flexible country on the one hand and Foreign/rigid country on the other hand.

comparison, where structural and stabilization gains are computed, and a welfare analysis based on the full transition path from heterogeneous to homogeneous labor markets, where I look at short-term and long-term welfare gains.

The convergence of the three parameters one at a time to their value in the Home (flexible) country shows that each has different consequences for the main variables in the Foreign (rigid) country. The convergence of the bargaining power of workers has the strongest positive effect, leading to higher wages, output and consumption, and lower unemployment. The convergence of the replacement rate of UI benefit has positive effects on output, consumption and unemployment but brings a small reduction in the real wage. Finally, the convergence of the firing cost parameter generates an increase of unemployment due to the induced rise of real wages. However, output and consumption also increase.

The results of a joint convergence of the three parameters to their values in the flexible country is a mix of the previous results. On impact, the effects of converging firing costs slightly dominates other effects. Low-productivity workers are fired as they become too costly. This slightly increases both wage and unemployment for a few periods. The increase in the wage is large enough to cause a rise in consumption. After a few periods, the positive effects of the joint decrease in UI benefits and the bargaining power of workers materialize. The real wage starts decreasing as the outside option and its share in the average wage drop. The resulting fall in the relative price of the Foreign good boosts the demand for the Foreign good, and the additional production requires more hires, which lowers unemployment. Over time, as job-seekers are harder to find, the wage increases again to finally exceed its initial level. Thus, output and consumption rise respectively by 7% and 3%, while unemployment drops by 25%. The Home (flexible) country suffers from the convergence in the short term, as a substitution effect towards the Foreign good takes place. However, the income effect implied by the dynamics of relative prices dominates in the long run: the fall of the relative price of the Foreign good increases the purchasing power of households of both countries.

As such, the reform generates a positive spillover effect for the Home (flexible) country. Therefore, in the long run, consumption, output and the real wage all increase in the Home country while unemployment shrinks.

The steady-state to steady-state comparison shows that labor-market convergence within the Euro Area brings structural welfare gains for the Foreign country and structural welfare losses for the Home country for most convergence scenarios under consideration. Furthermore, the higher the after-convergence labor-market flexibility, the higher the welfare gains. Indeed, on the one hand, a convergence towards a more flexible labor-market calibration lowers the unemployment rate and raises consumption for the Foreign country, which has positive welfare consequences. On the other hand, a convergence towards a more rigid calibration increases unemployment and decreases consumption for the Home country, generating welfare losses. The flexibilization of the labor-market of the Foreign country leads to a positive spillover effect that is strong enough to bring welfare gains for the Home country only for highly flexible after-convergence scenarios. On the opposite, the rigidification of the labor market of the Home country causes a negative spillover effect leading to welfare losses for the Foreign country for very high after-convergence rigidity levels. The Monetary Union as a whole experiences welfare gains for a broad range of flexibility levels. Structural gains are quite large, up to 1.6%, 0.4% and 1.1% of permanent per-capita consumption respectively for the Foreign country, the Home country and the Monetary Union.

Stabilization welfare gains follow a similar pattern. The Foreign country experiences gains and the Home country losses in most cases. Besides, the higher the after-convergence labor-market flexibility, the higher stabilization gains too. Indeed, converging towards more flexible labor markets entails lower firing costs, which leads to smoother movements in employment and less volatile unemployment rates. Therefore, the volatility of consumption is also lower, which brings stabilization gains. Moreover, labor-market convergence improves the fit of the union-wide monetary policy to local conditions, which induces stabilization gains for a greater range of after-convergence calibrations than structural gains. However, stabilization gains are smaller. The Foreign and the Home countries gain respectively up to 0.23% and 0.07% of permanent per-capita consumption for a convergence at a very high level of flexibility.

From a long-term perspective, the analysis of the full transition path does not really modify the insights resulting from the steady-state to steady-state analysis. Again, in this case, the Foreign country experiences welfare gains and the Home country suffers from welfare losses for most calibrations. Besides, the higher the level of the after-convergence flexibility of the labor markets, the higher total welfare gains. In the short term, the Foreign country gains in terms of welfare for any calibration. Indeed, the negative spillover effect coming from the rigidification of the labor market of the Home country takes time to materialize, which favors the Foreign country during the first periods. Thanks to this short-term effect of the transition, long-term welfare gains are experienced for a larger range of calibrations. The opposite mechanism applies to the Home country: it experiences short-term welfare losses whatever the after-convergence calibration. Only the substitution effect in favor of the Foreign good is present in the short-term, creating short-term welfare losses.

The chapter is organized as follows. Section 2 discusses the related literature and articulates the contribution of the chapter. Section 3 presents the monetary-union model with search and matching frictions. Section 4 discusses the parametrization and looks at the fit of the model to the data in terms of business cycle moments. The main results are examined in Section 5. Section 6 concludes.

1.2 Related literature

Labor-market institutions of Eurozone countries have been an important focus for more than two decades. The first interest was the higher regulation and protection of workers that existed in continental Europe compared to Anglo-Saxon countries and their consequences mainly in terms of unemployment. Nickell (1997) tries to understand which types of employment protection legislation tend to increase unemployment. He considers that three policies should be avoided: high unemployment benefits without time limit or government pressure on the unemployed individuals to get a job; a large unionization with collectively bargained wages or an absence of coordination between unions or employers for the bargaining of wages; and the combination of a too high minimum wage for young workers and high payroll taxes. Blanchard and Wolfers (2000) show that it is the interaction of adverse shocks with the European labor-market institutions that led to a higher unemployment in the European Union than in the United States from the end of the 1970s. Individuals remain often a longer time unemployed in Europe due to the more generous benefits and the higher employment protection. They also explain that the heterogeneity in unemployment levels inside Europe are due to differences in terms of employment protection legislation between countries as the shocks that affect them are quite similar from a country to another.

Therefore, authors have built models to try to better explain those results and to look at the consequences of legislation that are less protective of workers and unemployed individuals. For example, Ljunqvist and Sargent (2008) obtain the same conclusion as Blanchard and Wolfers (2000): in tranquil times (as in the 1950s and 1960s) the higher employment protection led to a lower unemployment level in Europe than in the United States. However, in a turbulent time (as from the late 1970s), it caused a persistently higher unemployment level in Europe. Indeed, high unemployment benefits are attractive for new unemployed individuals because their outside option is bigger. As high paid jobs become scarcer, workers get somewhat discouraged and decrease their search for new jobs. Blanchard and Giavazzi (2003) look, among other things, at the consequences of a decrease of the bargaining power of workers. They find that it leads to a lower wage, pushing firms to hire more workers. Thus, the unemployment rate decreases in the long run. Focusing more precisely on the Euro Area and the cross-country spillovers of labor-market reforms, Gomes et al. (2013)

show that a decrease in labor-market markup in Germany or Portugal would strongly increase output in each country and in the rest of the monetary union. Furthermore, if the reduction of labor-market markups was decided and implemented cooperatively in Eurozone countries, the effects would be stronger and more homogeneous among Eurozone members.

Other contributions focus on the timing of reforms. Cacciatore, Duval, et al. (2016) find that the adverse effects coming from a reduction of firing costs are much lower in a boom or in normal times than in a recession. On the contrary, output and employment increase more after a fall of unemployment benefits in the case of a recession than in normal times. Eggertsson, Ferrero, and Raffo (2014) find that labor-market reforms implemented when the interest rate is at the zero lower bound have very long-lasting adverse effects. They explain that, in this case and at least in the short run, a decrease of labor-market markups would have a contractionary effect on the economy. Indeed, the real interest rate would increase as agents expect the deflation to last, leading consumption to fall. Finally, Cacciatore and Fiori (2016) build a two-country monetary-union model where both countries are rigid and identical. They show that reforms increasing labor-market flexibility are positive in the long term and that synchronizing the reforms brings higher welfare gains. In the above papers, reforms apply to homogeneous countries while the question of cross-country heterogeneity is most likely critical, both in terms of the domestic and spillover effects and in terms of the political economy of labor-market reforms. The present chapter investigates the precise question of the domestic and spillover effects of labor-market convergence within an heterogeneous monetary union.

Historically, labor-market heterogeneity inside the Euro Area was not a main concern in the early stages of its creation. Dellas and Tavlas (2005) were among the firsts to investigate the repercussions of an asymmetry in terms of labor rigidity in the Euro Area using a three-country model. They find that if countries are perfectly symmetrical, they all benefit from belonging to a monetary union and, the higher the level of wage rigidity, the greater the welfare gains. But, when countries are heterogeneous in terms of wage rigidity, only the most rigid countries gain from entering a monetary union. Belonging to a currency union brings welfare losses to the relatively more flexible countries. Andersen and Seneca (2010) propose a two-country model with size, shock and structural asymmetries in a monetary union to look at the business cycle effects of asymmetries. The structural asymmetries include differences in terms of nominal rigidities and wage setting. They find very limited effects of those structural asymmetries at the union level but conclude that heterogeneoity matters at the country level. However, they do not focus on labor-market heterogeneity, which is the main focus of this chapter. Abbritti and Mueller (2013) use a model with search and matching to study the effects of asymmetries in terms of unemployment rigidities (employment protection legislation, hiring costs and matching technology) and wage rigidities (responsiveness of real wages) on inflation and unemployment differentials. They find that the larger the asymmetries, the higher the volatilities of inflation and unemployment differentials. Indeed, responses to shocks diverge as labor-market asymmetries grow. Differences in labor-market institutions thus generate more heterogeneous and more persistent business cycles. Kontogiannis (2015) uses a similar model to look at the optimal monetary policy in a monetary union when an asymmetry in terms of the degree of wage rigidity is present. He finds that such asymmetries generate welfare losses even under an optimal policy, due to a higher volatility of terms of trade. While these papers focus mostly on the cyclical effects of heterogeneity within a monetary union, the present chapter is more interested in the effects of structural convergence reforms.

As such, the present chapter is more closely related to the works of Dao (2013) and Poilly and Sahuc (2013). Dao (2013) builds a two-country DSGE model representing Germany on one hand and the other countries of the Euro Area on the other hand. She looks at the welfare consequences of modifying labor taxes, unemployment insurance benefits and the bargaining power of workers in the other countries to bring them closer to their level in Germany. She finds welfare gains for the different cases she studies except for a small decrease of labor taxes. Poilly and Sahuc (2013) also design a two-country model with nominal rigidities and search and matching frictions. The countries display differences in terms of labor-market institutions. They look at the welfare consequences of decreasing the separation rate and the bargaining power of workers, and of increasing the matching efficiency in France to equal their levels in Italy or the Netherlands. They find that increasing the flexibility of the French labor market has positive welfare consequences for France but also for the other country. In any case, these two papers consider complete financial markets, which prevents them from fully considering the potential wealth transfers within the union. In addition, both disregard some important characteristics of labor markets, such as firing costs. Last, they only consider convergence paths towards the most flexible country. The analysis offered in the next Sections deepens the analysis of the consequences of a convergence of the labor markets in Europe by modeling incomplete financial markets – therefore allowing for temporary wealth transfers – and considering a wider set of convergence scenarios for a wider set of labor-market parameters.

1.3 Model

The model consists of two countries in a Monetary Union: a Home country of size $n \in [0, 1]$ representing flexible countries of the Euro Area and a Foreign country of size $(1 - n)$ representing rigid countries. A unique central bank sets the nominal interest rate, while each government has an independent fiscal policy that consists in setting the tax rates and the unemployment insurance (UI hereafter) benefit scheme. Each government buys local varieties of goods and finances expenditure through labor and capital income taxes, and issues one-period nominal bonds. Individuals have preferences over a bundle of domestic and foreign goods with home bias, they supply labor and accumulate capital. Capital goods feature the same structure as consumption goods, with the same degree of home bias. Firms in each country produce internationally-traded varieties of goods using labor and capital. They face sticky prices *à la* Rotemberg while labor markets are subject to search and matching frictions with endogenous separation and firing costs. The real wage is Nash-bargained as usual in the literature. Individuals have access to two types of bonds: local government one-period nominal bonds and international nominal bonds. Union-wide financial markets are incomplete and households face a portfolio adjustment cost that ensures the model's stationarity. Countries are symmetric in structure but heterogeneous in terms of calibration. Therefore, this section only presents the details of the model from the perspective of the Home country. When needed, Foreign variables are denoted by an asterisk. Quantities are expressed per-capita.[5]

1.3.1 Households

In the Home country, there is a large family made of a continuum of n individuals as in Merz (1995).[6] A fraction $N_t = 1 - U_t$ is employed while the remaining portion U_t is unemployed and searching for jobs. Family members are insured against unemployment risk: members pool their income to achieve the same level of individual consumption. Family members derive utility from consumption C_t and from home production h when unemployed. The family head thus maximizes its utility $u(C_t, U_t)$:[7]

$$\max_{\substack{C_t, K_{t+1}, B_{t+1}, \\ B_{MU,t+1}}} E_t \Big[\sum_{t=0}^{\infty} \beta^t \frac{(C_t + hU_t)^{1-\gamma}}{1-\gamma} \Big] \tag{1.1}$$

subject to the budget constraint:

$$\begin{aligned} P_t C_t + P_t K_{t+1} + B_{t+1} + B_{MU,t+1} + P_t AC_t = R_t B_t + R_{MU,t} B_{MU_t} \\ + Div_t + (1 - \tau_t^W)\,(\chi_t U_t + W_t N_t) + (1 - \tau_t^K) R_{k,t} K_t + P_t K_t \Big[1 - (1 - \tau_t^K)\delta \Big] \end{aligned} \tag{1.2}$$

[5]Aggregate quantities can be easily obtained multiplying per-capita quantities by each country's size.
[6]The Foreign family counts $1 - n$ individuals.
[7]See Albertini and Fairise (2013) for a similar utility function. The presence of the home production h in the model is a standard way of generating empirically plausible fluctuations in the unemployment rate.

In the utility function, γ denotes the degree of relative risk aversion.[8] On the LHS of the budget constraint, P_t is the consumption price index, K_{t+1} the stock of physical capital at the end of period t and δ the depreciation rate. The last term $AC_t = \frac{\Gamma}{2}\left(\frac{B_{MU,t+1}}{P_t} - \frac{\bar{B}_{MU}}{P}\right)^2$ denotes the portfolio adjustment costs paid on union-wide bonds, where $\bar{B}_{MU}$ is the steady-state level of foreign assets.[9] Union-wide financial markets are thus incomplete, allowing for wealth transfers. On the RHS of the budget constraint, B_t is the amount of one-period government nominal bonds paying R_t between $t-1$ and t. Identically, $B_{MU,t}$ is the amount of union-wide bonds paying $R_{MU,t}$ between $t-1$ and t. Div_t is the profit of the monopolistic firms indexed in i with $Div_t = \frac{1}{n}\int_0^n Div_t(i)di$, W_t is the average pre-tax nominal wage received by workers, τ_t^W is the tax rate on labor income, and χ_t is the pre-tax UI benefits. Finally, $R_{k,t}$ is the pre-tax rate of return on capital and τ_t^K is the capital income tax, that comes with a deduction on depreciated capital. First-order conditions with respect to C_t, K_{t+1} B_{t+1} and $B_{MU,t+1}$ imply:

$$\beta E_t\left\{\left(\frac{C_t + hU_t}{C_{t+1} + hU_{t+1}}\right)^\gamma\left[1 + (1-\tau_{t+1}^K)\left(\frac{R_{k,t+1}}{P_{t+1}} - \delta\right)\right]\right\} = 1 \tag{1.3}$$

$$\beta E_t\left[\frac{P_t(C_t + hU_t)^\gamma}{P_{t+1}(C_{t+1} + hU_{t+1})^\gamma}R_{t+1}\right] = 1 \tag{1.4}$$

$$\beta E_t\left[\frac{P_t(C_t + hU_t)^\gamma}{P_{t+1}(C_{t+1} + hU_{t+1})^\gamma}\frac{R_{MU,t+1}}{1 + \Gamma\left(\frac{B_{MU,t+1}}{P_t} - \frac{\bar{B}_{MU}}{P}\right)}\right] = 1 \tag{1.5}$$

Per-capita consumption, investment and adjustment costs are defined as Armington aggregators of Home and Foreign goods:

$$\nu_t = \left[\alpha^{\frac{1}{\phi}}(\nu_{H,t})^{\frac{\phi-1}{\phi}} + (1-\alpha)^{\frac{1}{\phi}}(\nu_{F,t})^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}} \tag{1.6}$$

[8] Since my quantitative exercises use either second-order approximations or non-linear solutions, certainty equivalence will not hold and γ will be a key parameter.

[9] As shown by Schmitt-Grohé and Uribe (2003), these costs must be introduced to make the model stationary.

for $\nu = \{C, I, AC\}$. Variables ν_H and ν_F respectively stand for the quantities of Home and Foreign goods in the bundles, ϕ is the trade elasticity and $\alpha \in [0.5, 1]$ expresses the preference for national goods.[10] Per-capita quantities of Home and Foreign goods are defined by the following bundles of varieties:

$$\nu_{H,t} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\psi}} \int_0^n \nu_{h,t}(i)^{\frac{\psi-1}{\psi}} di \right]^{\frac{\psi}{\psi-1}} \tag{1.7}$$

$$\nu_{F,t} = \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\psi}} \int_n^1 \nu_{f,t}(i)^{\frac{\psi-1}{\psi}} di \right]^{\frac{\psi}{\psi-1}} \tag{1.8}$$

where $\nu_{h,t}(i)$ and $\nu_{f,t}(i)$ denote differentiated varieties of Home and Foreign goods, and ψ is the elasticity of substitution among varieties. We assume that the law of one price holds. Since countries have a common currency, the Home consumption price index is:

$$P_t = \left[\alpha (P_{H,t})^{1-\phi} + (1-\alpha)(P_{F,t})^{1-\phi} \right]^{\frac{1}{1-\phi}} \tag{1.9}$$

with $P_{H,t}$ and $P_{F,t}$ given by

$$P_{H,t} = \left[\left(\frac{1}{n} \right) \int_0^n P_{h,t}(i)^{1-\psi} di \right]^{\frac{1}{1-\psi}} \tag{1.10}$$

$$P_{F,t} = \left[\left(\frac{1}{1-n} \right) \int_n^1 P_{f,t}(i)^{1-\psi} di \right]^{\frac{1}{1-\psi}} \tag{1.11}$$

[10] Parameters α and α^* are defined according to the intra-EMU degree of openness $(1-\tilde{\alpha})$ in the following way $(1-\alpha) = (1-n)(1-\tilde{\alpha})$ and $(1-\alpha^*) = n(1-\tilde{\alpha})$.

where $P_{h,t}(i)$ and $P_{f,t}(i)$ are respectively the price of Home and Foreign varieties. Optimization yields the following variety demands:

$$\nu_{h,t}(i) = \frac{\alpha}{n}\left(\frac{P_{H,t}}{P_t}\right)^{-\phi}\left(\frac{P_{h,t}(i)}{P_{H,t}}\right)^{-\psi}(n\nu_t) \tag{1.12}$$

$$\nu^*_{h,t}(i) = \frac{1-\alpha^*}{n}\left(\frac{P_{H,t}}{P^*_t}\right)^{-\phi}\left(\frac{P_{h,t}(i)}{P_{H,t}}\right)^{-\psi}((1-n)\,\nu^*_t) \tag{1.13}$$

$$\nu_{f,t}(i) = \frac{1-\alpha}{1-n}\left(\frac{P_{F,t}}{P_t}\right)^{-\phi}\left(\frac{P_{f,t}(i)}{P_{F,t}}\right)^{-\psi}(n\nu_t) \tag{1.14}$$

$$\nu^*_{f,t}(i) = \frac{\alpha^*}{1-n}\left(\frac{P_{F,t}}{P^*_t}\right)^{-\phi}\left(\frac{P_{f,t}(i)}{P_{F,t}}\right)^{-\psi}((1-n)\,\nu^*_t) \tag{1.15}$$

1.3.2 Firms

In the Home country, a continuum of monopolistic firms indexed by n use labor and capital to produce a variety of a final good.

The labor market

The labor market is subject to search and matching frictions.[11] The large family is divided between employed and unemployed. I consider that labor is immobile across countries. At each period, a job faces an exogenous productivity shock A_t and an idiosyncratic shock a_t. The exogenous productivity shock is defined such that: $A_t = A^{\eta}_{t-1}\overline{A}^{1-\eta}\epsilon_{A,t}$, with $\epsilon_{A,t}$ an iid shock. The idiosyncratic shock follows a uniform distribution on the interval $[0,1]$ with c.d.f. $G(\cdot)$. Employment in period t is composed of new and old workers. New workers matched at the end of period $t-1$ become productive in the next period with idiosyncratic productivity a^N. Old workers are those who were previously matched and survived the separation process. At the beginning of each period, first, exogenous separations occur with a probability ρ^x. Then, for $\rho^n_t = G(\underline{a}_t)$ of the remaining jobs, a_t falls below the

[11] For this part of the model, I mostly follow the models in Thomas (2006) and Zanetti (2011) to which I add capital.

endogenous profitability threshold $\underline{a}_t$ and the job is destroyed. As a consequence, the firm fires the worker and has to pay a firing cost F. Therefore, total job-separation rate is expressed as $\rho_t = \rho^x + (1-\rho^x)\rho_t^n$. To sum up, the aggregate law of motion of employment is defined as:

$$N_t = (1-\rho^x)(1-\rho_t^n)N_{t-1} + M_{t-1} \tag{1.16}$$

where N_t is the beginning-of-period employment and M_t is the number of matches formed during period t. New matches are formed according to a standard Cobb-Douglas matching function:

$$M_t = m(V_t)^{1-\mu}(U_t)^{\mu} \tag{1.17}$$

where $V_t = \frac{1}{n}\int_0^n V_t(i)\ di$ is the number of vacancies, m captures the efficiency of the matching process, and $\mu \in [0,1]$ is the matching elasticity. Defining $\theta_t = V_t/U_t$ as labor-market tightness from the firms' point of view, the job-filling rate is the ratio of the number of new matches over the number of vacancies:

$$q(\theta_t) \equiv \frac{M_t}{V_t} = m\theta_t^{-\mu} \tag{1.18}$$

and the job-finding rate is the ratio of total new hires over the number of unemployed individuals:

$$p(\theta_t) \equiv \frac{M_t}{U_t} = m\theta_t^{1-\mu} \tag{1.19}$$

Firms' Production

When a working relation gets productive, each firm produces units of a final good using labor and capital according to the following technology function

$$Y_t(i) = A_t a_t K_t(i)^{\zeta} N_t(i)^{1-\zeta} \tag{1.20}$$

with $K_t(i)$ and $N_t(i)$ defined such that $K_t = \frac{1}{n}\int_0^n K_t(i)\, di$ and $N_t = \frac{1}{n}\int_0^n N_t(i)\, di$. Firms take into account the demands for local varieties expressed by individuals and governments when setting their prices $P_{h,t}(i)$. Their objective is to maximize the profits they rebate to the family through dividends:

$$E_s \sum_{s=t}^{\infty} Q_{t+s} \Bigg\{ \frac{P_{h,t+s}(i)}{P_{H,t+s}} Y_{t+s}(i) - \frac{R_{k,t+s}}{P_{H,t+s}} K_{t+s}(i) - \frac{W_{k,t+s}}{P_{H,t+s}} N_{t+s}(i)$$
$$- \left[\frac{\kappa_p}{2} \left(\frac{P_{h,t+s}(i)}{P_{h,t+s-1}(i)} - 1 \right)^2 \right] Y_{t+s} - \kappa_v V_{t+s}(i) - (1-\rho^x) G(\underline{a}_{t+s}) N_{t+s}(i) F \Bigg\} \quad (1.21)$$

where $\frac{P_{h,t+s}(i)}{P_{H,t+s}} Y_{t+s}(i)$ is total firm revenue and $Q_{t+s} = \beta \frac{P_t}{P_{t+s}} \left(\frac{C_t + hU_t}{C_{t+s} + hU_{t+s}} \right)^{\gamma}$ is the stochastic discount factor between t and $t+s$. In addition, κ_v is the unit cost of a vacancy. Finally, $\frac{\kappa_p}{2}\left[\frac{P_{h,t}(i)}{P_{h,t-1}(i)} - 1\right]^2 Y_t$ are adjustment costs paid at each change of price (see Rotemberg (1982)), with $\kappa_p > 0$ a measure of price stickiness. Further, the optimal choice of $P_{h,t}(i)$ maximizes the expected stream of dividends subject to the condition that the production equals the demand for the firm's goods :[12]

$$Y_t(i) = \left(\frac{P_{h,t}(i)}{P_{H,t}} \right)^{-\psi} \Bigg[\alpha \left(\frac{P_{H,t}}{P_t} \right)^{-\phi} (C_t + I_t + AC_t) + \frac{1-n}{n} (1-\alpha^*) \left(\frac{P_{H,t}}{P_t^*} \right)^{-\phi} (C_t^* + I_t^* + AC_t^*)$$
$$+ G_t + \kappa_v V_t + \frac{\kappa_p}{2} \left(\frac{P_{h,t}(i)}{P_{h,t-1}(i)} - 1 \right)^2 Y_t + (1-\rho^x) G(\underline{a}_t) N_t(i) F \Bigg] \quad (1.22)$$

Then, I take the derivative of Equation (1.21) subject to Equation (1.20) with respect to $P_{h,t}(i)$. As every firm sets the same new price in equilibrium, we have $P_{h,t}(i) = P_{H,t}$. This allows us to obtain the following New Keynesian Phillips curve, that determines the evolution of the producer price index inflation $\pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$:

$$(1-\psi) + \psi MC_t + E_t Q_{t+1} \kappa_p (\pi_{H,t+1} - 1) \pi_{H,t+1} Y_{t+1} / Y_t = \kappa_p (\pi_{H,t} - 1) \pi_{H,t} \quad (1.23)$$

[12] A similar expression holds for the Foreign firm.

where the real marginal cost MC_t is the Lagrange multiplier associated with Equation (1.20). Finally, I derive the first-order condition on the stock of capital:

$$\zeta MC_t Y_t(i) = \frac{R_{k,t}}{P_{H,t}} K_t(i) \tag{1.24}$$

Wage determination

The wage is determined through a Nash-bargaining process that involves the values for each firm of a vacancy and of a filled job as well as the values for individuals of being employed and of being unemployed. An unemployed individual receives net unemployment benefits and the value of home production. He finds a job with probability $p(\theta_t)$. Thus, the present-discounted value of unemployment $\mathscr{U}_t$ is:

$$\mathscr{U}_t = (1-\tau_t^W)\frac{P_{H,t}}{P_t}\frac{\chi_t}{P_{H,t}} + h + E_t Q_{t+1}\Big[p(\theta_t)\mathscr{W}_{t+1}^N + [1-p(\theta_t)]\mathscr{U}_{t+1}\Big] \tag{1.25}$$

Workers earn a different real wage whether they are new hires $w_t^N = \frac{W_t^N}{P_{H,t}}$ or old matches $w_t(a_t) = \frac{W_t(a_t)}{P_{H,t}}$. The present-discounted values of a new match $\mathscr{W}_t^N$ and an old match $\mathscr{W}_t(a_t)$ depend on their respective wage and the continuation term. They are defined as:

$$\mathscr{W}_t^N = (1-\tau_t^W)\frac{P_{H,t}}{P_t} w_t^N + E_t Q_{t+1}\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) + \rho_{t+1}\mathscr{U}_{t+1}\Big] \tag{1.26}$$

$$\mathscr{W}_t(a_t) = (1-\tau_t^W)\frac{P_{H,t}}{P_t} w_t(a_t) + E_t Q_{t+1}\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) + \rho_{t+1}\mathscr{U}_{t+1}\Big] \tag{1.27}$$

When looking for workers, firms post vacancies at a unit cost κ_v. They get filled with a probability $q(\theta_t)$ for a gain $\mathscr{J}_{t+1}^N$. Hence, the present-discounted value of a vacancy $\mathscr{V}_t$ is:

$$\mathscr{V}_t = -\kappa_v + E_t Q_{t+1}\Big[q(\theta_t)\mathscr{J}_{t+1}^N + [1-q(\theta_t)]\mathscr{V}_{t+1}\Big] \tag{1.28}$$

Finally, using the first-order derivative of Equation (1.21), price symmetry among firms and free entry,[13] I obtain the present-discounted value of a new match $\mathscr{J}_t^N$ and of an old match $\mathscr{J}_t(a_t)$ that are identical for all firms:

$$\begin{aligned}\mathscr{J}_t(a_t) &= (1-\zeta)MC_tA_ta_tK_t^{\zeta}N_t^{-\zeta} - w_t(a_t)\\ &\quad + E_tQ_{t+1}(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^{1} \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) - G(\underline{a}_{t+1})F\Big]\end{aligned} \tag{1.29}$$

$$\begin{aligned}\mathscr{J}_t^N &= (1-\zeta)MC_tA_ta^NK^{\zeta}N_t^{-\zeta} - w_t^N\\ &\quad + E_tQ_{t+1}(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^{1} \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) - G(\underline{a}_{t+1})F\Big]\end{aligned} \tag{1.30}$$

This value corresponds to the marginal profit that the firm obtains from a filled job at period t plus the continuation value. Following Mortensen and Pissarides (2003), a match is profitable from the point where $\mathscr{J}_t(\underline{a}_t) + F = 0$, as otherwise the firm fires the worker and must pay the firing costs. As a consequence, using Equation (1.29) at the productivity level $\underline{a}_t$, I obtain the expression defining the marginal cost as the wage minus the firing cost and the usual continuation term divided by the marginal product of labor:

$$MC_t = \frac{w_t(\underline{a}_t) - F - E_tQ_{t+1}(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^{1} \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) - G(\underline{a}_{t+1})F\Big]}{(1-\zeta)A_t\underline{a}_tK^{\zeta}N_t^{-\zeta}} \tag{1.31}$$

As it is common in the literature, the real wage is determined through a Nash-bargaining solution involving the maximization of total surplus. The latter is a geometric average of the surplus of workers and the one of firms, weighted by their relative bargaining power $\sigma \in [0;1]$:

$$w_t(a_t) \;=\; arg\ max\ (\mathscr{W}_t(a_t) - \mathscr{U}_t)^{\sigma}(\mathscr{J}_t(a_t) + F)^{1-\sigma} \tag{1.32}$$

$$w_t^N \;=\; arg\ max\ (\mathscr{W}_t^N - \mathscr{U}_t)^{\sigma}(\mathscr{J}_t^N)^{1-\sigma} \tag{1.33}$$

[13] Free entry implies that $\mathscr{V} = 0$ for any t.

The solutions imply respectively:[14]

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}(\mathscr{J}_t(a_t)+F) = (1-\sigma)(\mathscr{W}_t(a_t)-\mathscr{U}_t) \tag{1.34}$$

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\mathscr{J}_t^N = (1-\sigma)(\mathscr{W}_t^N-\mathscr{U}_t) \tag{1.35}$$

After simplifications, I obtain the determination of the real wage for old and new workers:

$$\begin{aligned} w_t(a_t) = \sigma\Big[&MC_t(1-\zeta)K_t^\zeta N_t^{-\zeta}A_t a_t + \theta_t\kappa_v + (1-E_tQ_{t+1}(1-\rho^x))F\Big] \\ &+ (1-\sigma)\Big(\frac{\chi_t}{P_{H,t}} + \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}}\Big) \end{aligned} \tag{1.36}$$

$$\begin{aligned} w_t^N = \sigma\Big[&MC_t(1-\zeta)K_t^\zeta N_t^{-\zeta}A_t a^N + \theta_t\kappa_v - E_tQ_{t+1}(1-\rho^x)F\Big] \\ &+ (1-\sigma)\Big(\frac{\chi_t}{P_{H,t}} + \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}}\Big) \end{aligned} \tag{1.37}$$

As usual, the real wage settles somewhere between the marginal productivity of labor plus the rent of a position filled – the upper bound – and the outside option for workers – the lower bound – that depends on UI benefits and the home production term. Wages differ by the compensation σF for the savings on firing costs that only old matches receive.

Substituting Equation (1.36) into (1.29), and Equation (1.37) into (1.30), I obtain new expressions of the firms' surplus coming from old and new matches:

$$\begin{aligned} \mathscr{J}_t(a_t)+F = (1-\sigma)\Big[&(1-\zeta)MC_tA_ta_tK_t^\zeta N_t^{-\zeta} - \frac{\chi_t}{P_{H,t}} - \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}} + (1-E_tQ_{t+1}(1-\rho^x)F\Big] \\ &- \sigma\theta_t\kappa_v + E_tQ_{t+1}(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^1 \big(\mathscr{J}_{t+1}(a_{t+1})+F\big)dG(a_{t+1})\Big] \end{aligned} \tag{1.38}$$

[14]Details to obtain those results as well as the job destruction and job creation conditions below are presented in the technical Appendix

$$\mathscr{J}_t^N = (1-\sigma)\Big[(1-\zeta)MC_tA_ta^NK_t^{\zeta}N_t^{-\zeta} - \frac{\chi_t}{P_{H,t}} - \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}} - E_tQ_{t+1}(1-\rho^x)F\Big]$$
$$- \sigma\theta_t\kappa_v + E_tQ_{t+1}(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^{1}\big(\mathscr{J}_{t+1}(a_{t+1})+F\big)dG(a_{t+1})\Big] \quad (1.39)$$

Then, using the fact that $\mathscr{J}_t(\underline{a}_t)+F=0$, I can write:

$$\begin{aligned}\mathscr{J}_t(a_t)+F &= \mathscr{J}_t(a_t)+F-(\mathscr{J}_t(\underline{a}_t)+F)\\ &= (1-\sigma)(1-\zeta)MC_tK_t^{\zeta}N_t^{-\zeta}A_t(a_t-\underline{a}_t)\end{aligned} \quad (1.40)$$

$$\begin{aligned}\mathscr{J}_t^N &= \mathscr{J}_t^N-(\mathscr{J}_t(\underline{a}_t)+F)\\ &= (1-\sigma)\Big[(1-\zeta)MC_tK_t^{\zeta}N_t^{-\zeta}A_t(a^N-\underline{a}_t)-F\Big]\end{aligned} \quad (1.41)$$

Thanks to Equations (1.41) and (1.28), I obtain the job creation condition:

$$\frac{\kappa_v}{q(\theta_t)} = (1-\sigma)E_tQ_{t+1}\Big[(1-\zeta)MC_{t+1}K_{t+1}^{\zeta}N_{t+1}^{-\zeta}A_{t+1}(a^N-\underline{a}_{t+1})-F\Big] \quad (1.42)$$

Finally, using Equation (1.40), I get the job destruction condition:

$$MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t\underline{a}_t + (1-E_tQ_{t+1}(1-\rho^x))F - \frac{\chi_t}{P_{H,t}} - \frac{P_t}{P_{H,t}}\frac{h_t}{1-\tau_t^W} - \frac{\sigma}{1-\sigma}\theta_t\kappa_v$$
$$+ E_tQ_{t+1}(1-\rho^x)MC_{t+1}(1-\zeta)K_{t+1}^{\zeta}N_{t+1}^{-\zeta}A_{t+1}\int_{\underline{a}_{t+1}}^{1}(a_{t+1}-\underline{a}_{t+1})dG(a_{t+1}) = 0 \quad (1.43)$$

1.3.3 Governments

Government expenditure and UI benefits are financed through taxes on capital and labor, public debt and firing costs. The Home government consumes only local goods and government bond markets are fully segmented, *i.e.* purchased nationally. Therefore, the government has the following budget constraint, expressed in real terms:

$$G_t + (1-\tau_t^W)\frac{\chi_t}{P_{H,t}}U_t + R_t\frac{B_t}{P_{H,t}} = \Big(\frac{R_{k,t}}{P_{H,t}} - \frac{P_t}{P_{H,t}}\delta\Big)K_t\tau_t^K + \frac{W_t}{P_{H,t}}N_t\tau_t^W + \frac{B_{t+1}}{P_{H,t}} \tag{1.44}$$

where G_t is government expenditure.[15] As the government issues nominal debt, it needs a feedback rule in order to produce stationary dynamics. I assume that government spending follows a simple feedback rule:

$$G_t = s_g\bar{Y} - \phi^b(B_t - \bar{B}) \tag{1.45}$$

where s_g is the steady-state share of government spending in GDP, ϕ^b determines the speed of debt stabilization, and $\bar{B}$ is the steady-state level of debt.

1.3.4 Central Bank

I define the union-wide inflation rate π^{MU} as a geometric weighted average of the Home CPI $\pi = P_t/P_{t-1}$ and the Foreign CPI $\pi^* = P_t^*/P_{t-1}^*$:

$$\pi_t^{MU} = \pi_t^n(\pi_t^*)^{1-n} \tag{1.46}$$

The central bank has control over the nominal interest rate of the union-wide bond R_{MU}. It is set according to the following Taylor-type rule, close to the actual European Central

[15]The latter are defined as:

$$G_t = \left[\left(\frac{1}{n}\right)^{\frac{1}{\psi}}\int_0^n (G_t(i))^{\frac{\psi-1}{\psi}}di\right]^{\frac{\psi}{\psi-1}}$$

The corresponding variety demands are therefore

$$G_t(i) = \frac{1}{n}\left(\frac{P_{h,t}(i)}{P_{H,t}}\right)^{-\psi}G_t$$

Bank objectives:

$$log\left(\frac{R_{MU,t}}{\bar{R}_{MU}}\right) = \rho_i \ log\left(\frac{R_{MU,t-1}}{\bar{R}_{MU}}\right) + (1-\rho_i)\phi_i \ log\left(\frac{\pi_t^{MU}}{\bar{\pi}^{MU}}\right) \tag{1.47}$$

where ρ_i expresses the persistence of the interest rate and $\phi_i > 1$ determines the strength of the response of $R_{MU,t}$ to the inflation gap.

1.3.5 Equilibrium

In a symmetric equilibrium, the per-capita wage is a weighted average of wages of old and new matches. Therefore, we have:

$$\begin{aligned} w_t = \sigma\Big[&MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t\tilde{a}_t + \theta_t\kappa_v + (\omega_t^O - E_tQ_{t+1}(1-\rho^x))F\Big] \\ &+ (1-\sigma)\Big(\frac{\chi_t}{P_{H,t}} + \frac{h_t}{1-\tau_t^W}\Big) \end{aligned} \tag{1.48}$$

where $\omega_t^O = (1-\rho_t)N_{t-1}/N_t$ is the weight of old matches.[16] In addition, $\tilde{a} = \omega_t^O H(a_t)+(1-\omega_t^O)a_t^N$ is the average idiosyncratic productivity for all jobs with $H(\underline{a}_t) = \int_{\underline{a}_t}^1 a_t f(a_t)/(1-G(\underline{a}_t))da_t = E(a_t|a_t > \underline{a}_t)$ the average idiosyncratic productivity among continuing jobs. Furthermore, the per-capita production is $Y_t = A_t\tilde{a}_tK_t^{\zeta}N_t^{1-\zeta}$.

Then, to close the model, we need to use the variety demand Equation (1.22) and its foreign counterpart, and aggregate over varieties to get:

$$\begin{aligned} \Big[1-\frac{\kappa_p}{2}(\pi_{H,t}-1)^2\Big]Y_t &= \alpha\Big(\frac{P_{H,t}}{P_t}\Big)^{-\phi}(C_t+I_t+AC_t) \\ &+ \frac{1-n}{n}(1-\alpha^*)\Big(\frac{P_{H,t}}{P_t^*}\Big)^{-\phi}(C_t^*+I_t^*+AC_t^*) + G_t + \kappa_vV_t + (1-\rho^x)G(\underline{a}_t)N_tF \end{aligned} \tag{1.49}$$

[16] Thus, the weight of new matches is $1-\omega_t^O$.

$$\Big[1-\frac{\kappa_p}{2}(\pi_{F,t}-1)^2\Big]Y_t^* = \alpha^*\Big(\frac{P_{F,t}}{P_t^*}\Big)^{-\phi}(C_t^*+I_t^*+AC_t^*)$$
$$+\frac{n}{1-n}(1-\alpha)\Big(\frac{P_{F,t}}{P_t}\Big)^{-\phi}(C+I+AC_t)+G_t^*+\kappa_v^*V_t^*+(1-\rho^{x*})G(\underline{a}_t^*)N_t^*F^* \quad (1.50)$$

The clearing condition on the union-wide bond market is

$$n\frac{B_{MU,t}}{P_t}+RER_t(1-n)\frac{B^*_{MU,t}}{P_t^*}=0 \quad (1.51)$$

where RER_t is the real exchange rate defined as $RER_t = P_t^*/P_t$. Finally, aggregating all budget constraints yields the dynamics of foreign assets of the domestic economy:

$$\frac{B_{MU,t+1}}{P_t}-R_{MU,t}\frac{B_{MU,t}}{P_t}=\frac{P_{H,t}}{P_t}\Big[\big(1-\frac{\kappa_p}{2}(\pi_{H,t}-1)^2\big)Y_t-G_t-\kappa_vV_t-(1-\rho^x)G(\underline{a}_t)N_tF\Big]-C_t-I_t-AC_t \quad (1.52)$$

Finally, for future reference, I define the terms of trade as:

$$T_t=\frac{P_{F,t}}{P_{H,t}} \quad (1.53)$$

1.4 Calibration, solution, and business cycle moments

Size. To calibrate my model, I choose to use the countries that joined the Euro Area before 2002 and separate them according to their unemployment rate in 2017 as shown in Figure 1.5 in Appendix. Countries with a unemployment rate lower than the average of the Eurozone (Austria, Belgium, Finland, Germany, Ireland, Luxembourg and the Netherlands) compose the Home or flexible country. Countries with a higher unemployment rate (France, Greece, Italy, Portugal and Spain) compose the Foreign or rigid country. The size of each country represents the labor force of each region of the Euro Area: the Home (flexible) country has a size $n = 0.43$ and the Foreign (rigid) country $1 - n = 0.57$.

Preferences, trade and openness. The period is a quarter, as our business cycle matching exercise will use quarterly data. Hence, β is calibrated to 0.99, which implies an annualized steady-state nominal interest rate of roughly 4%. I assumed that inflation rates have no trends, therefore $\bar{\pi} = \bar{\pi}^* = \bar{\pi}_H = \bar{\pi}^*_F = \bar{\pi}^{MU} = 1$. Further, according to OECD data, both groups of countries have a similar weighted average productivity. Therefore, I set $\bar{A} = \bar{A}^* = 1$. I consider that $\bar{B}_{MU} = \bar{B}^*_{MU} = 0$, both in the initial and the final steady state. As such, temporary wealth transfers may occur along the business cycle or along a transition path, but may not be permanent. This condition implies that trade balances are zero in steady states, and that terms of trade adjust to $\bar{T} = 1.029$ in the initial steady state. Risk aversion γ is set at 1.5 as in Christoffel, Kuester, and Linzert (2009) and many others. I choose the same value as in Schmitt-Grohé and Uribe (2003) concerning portfolio adjustment cost: $\Gamma = 0.0007$ to imply an annual interest rate premium of 3%.[17] Based on intra-EMU trade openness data, the intra-EMU import share is $(1 - \tilde{\alpha}) = 30\%$. It implies $\alpha = 0.829$ and $\alpha^* = 0.871$. The value of the trade elasticity remains debated in the literature, with very different values used in the DSGE literature and the literature on international trade. I choose a relatively low value of $\phi = 2$ as in Obstfeld and Rogoff (2005).[18]

Production. The depreciation rate of capital is $\delta = 0.025$ to match a 10% yearly depreciation. The capital share is set to $\zeta = 0.36$ which is a usual value in the literature. The elasticity of substitution between varieties ψ is set to 6 as in Brückner and Pappa (2012) in order to have a gross steady-state markup of 20%. I choose $\kappa_p = 60$ which is a plausible value as suggested by Ireland (2001), Keen and Wang (2007), or Born and Pfeifer (2016), among others.

Labor markets. I set the elasticity of the matching function to $\mu = 0.5$ in both countries,

[17] As a robustness check, the results of the transition exercise are also computed for other values of Γ in Appendix 1.7.4.

[18] As a sensitivity analysis, I compute the results of the transition exercise for other values of ϕ in Appendix 1.7.4.

which belongs to the range of credible values as described in Petrongolo and Pissarides (2001). The calibration of the bargaining power of workers greatly varies in the literature. I set it to better match second-order moments of the unemployment rate and comply with the differences between countries that are shown in the data.[19] I choose $\sigma = 0.7$ and $\sigma^* = 0.8$. I assume that new workers enter with an idiosyncratic productivity of 0.4 to better match the volatility of unemployment. I calculate the separation rates using the data from Hobijn and Şahin (2009), building the labor-force weighted average of each region. I obtain $\rho = 0.0316$ and $\rho^* = 0.0286$.[20] Then, following Albertini and Fairise (2013), I choose exogenous separations to be twice more frequent than endogenous ones at the steady-state. Therefore, I get: $\bar{\rho}^n = 0.0106$ and $\rho^x = 0.0212$ for the Home country, and $\bar{\rho}^n = 0.0096$ and $\rho^x = 0.0192$ for the Foreign country. Further, I design the calibration so that steady-state unemployment levels are equal to the average unemployment rate weighted by the labor force in both areas of the Eurozone between the second quarter of 1998 and the first quarter of 2017: $\bar{U} = 7.02\%$ in the flexible area and $\bar{U}^* = 11.37\%$ in the rigid area. To hit those targets, I impose $\bar{p}(\theta) = 0.418$ and $\bar{p}(\theta)^* = 0.223$. Further, the steady-state job-filling rate is imposed at $\bar{q}(\theta) = 0.7$ in the flexible country and $\bar{q}(\theta)^* = 0.6$ in the rigid country which are slightly lower values than the one used in Den Haan, Ramey, and Watson (2000) for the United States. I use the data of Esser et al. (2013) to compute a labor-force weighted average of the net UI benefit replacement rates. I obtain $\frac{\chi}{\bar{w}} = 61\%$ and $\frac{\chi^*}{\bar{w}^*} = 65\%$. Other parameters of the model are chosen to deliver the above targets: home production parameters are respectively $h = 0.1095$ and $h^* = 0.1222$, the vacancy cost parameters are respectively $\kappa_v = 0.0388$ and $\kappa_v^* = 0.0084$. Besides, this calibration gives the following values for the matching efficiency parameter: $m = 0.5409$ and $m^* = 0.3658$. Finally, the Employment Protection Legislation database of the OECD shows that the administrative costs to fire a worker are higher for the Foreign country. Moreover, firing costs are usually

[19] The bargaining power of workers summarizes the union density, the union coverage, and the coordination in wage bargaining between unions and between employers. The three characteristics tend to be higher in rigid countries of the Euro Area (see Nickell (1997)).

[20] I exclude Spain from the calculation for the Foreign country as its value is a clear outlier.

set between a one-month and a two-month wage in the literature for continental Europe.[21] As such I calibrate the firing costs to get $\frac{F}{\bar{w}} = 45\%$ and $\frac{F^*}{\bar{w}^*} = 65\%$ in the steady state.

Policy. The shares of government consumption in GDP s_g are set to 0.18 in both countries. Moreover, I choose $\phi^b = 0.1$, which means that more than half of the deviation of debt to its steady-state value is closed in two years. I follow Christoffel, Kuester, and Linzert (2009) for the monetary rule by setting the persistence at $\rho_i = 0.85$ and the response to inflation at $\phi_i = 1.5$. Finally, the steady-state tax rates on capital and labor income are computed using data from Trabandt and Uhlig (2013). I use country-level tax rates to calculate GDP-weighted average tax rates for each zone, which gives $\tau^K = 27\%$ and $\tau^{K*} = 38\%$ for the capital income tax and $\tau^W = 0.35$ and $\tau^{W*} = 0.34$ for the labor income tax.

Shocks. I set the persistence of productivity shocks at $\eta = \eta^* = 0.9$ and their volatility at $std(\epsilon_{a,t}) = std(\epsilon^*_{a,t}) = 0.9\%$ to better match absolute volatility of output. Finally, the cross-country correlation of shocks is 0.7. Table 1.1 below summarizes my parameter values.

Solution and second-order moments. The model is solved using second-order perturbation methods.[22] I first compare the implied second-order moments of important variables with those of the data to gauge the quality of the model. Empirical second-order moments were obtained using the OECD database. I use quarterly data from 1998Q2 to 2017Q1. For unemployment rates, I build labor force weighted averages. The moments are computed on HP-filtered series taken in logs with a smoothing parameter of 1600.

Table 2 shows that the moments of the model match fairly well those of the data.[23] Although the volatility of consumption is lower in the model, relative standard deviations are well reproduced.[24] The relative volatility is always higher for Foreign variables both in the model

[21] The calibration of the firing costs as 30% of the quarterly wage in Zanetti (2011) for the United Kingdom can be considered a lower-bound.

[22] I use the Dynare setup (see Adjemian et al. (2011)).

[23] I look more precisely at the drivers of volatilities in Appendix 1.7.2.

[24] Note that consumption only comprises non-durable goods in the model while the data add durable and non-durable goods. The discrepancy in the volatility of consumption is therefore easily explained.

Table 1.1: Calibration for the baseline model

Parameters	**Symbol**	**Home**	**Foreign**
Discount factor	β	0.99	
Degree of risk aversion	γ	1.5	
Depreciation rate of capital	δ	0.025	
Portfolio intermediation costs	Γ	0.0007	
Elasticity of substitution between varieties	ψ	6	
Trade elasticity	ϕ	2	
Parameter of the production function	ζ	0.36	
Persistence of the productivity shocks	η	0.90	
Rotemberg cost parameter	κ_p	60	
Match elasticity	μ	0.5	
Share of government consumption	υ	0.18	
Persistence of the interest rate	ρ_i	0.85	
Parameter associated with π^{MU}	ϕ_i	1.5	
Policy parameter	ϕ_b	0.1	
Tax rate on capital	τ^K	0.27	0.38
Tax rate on labor	τ^W	0.35	0.34
Country size	n	0.43	0.57
Home bias	α	0.829	0.871
Vacancy cost	κ_v	0.0388	0.0084
Value of home production	h	0.1095	0.1222
Matching efficiency parameter	m	0.5409	0.3658
Firing cost	F	0.2575	0.3613
Bargaining power of workers	σ	0.7	0.8
Exogenous separation rate	ρ^x	0.0212	0.0192
Unemployment Insurance benefit	χ	0.3490	0.3613
Labor-market variables	**Symbol**	**Home**	**Foreign**
Steady-state unemployment rate	$\bar{U}$	0.0702	0.1137
Steady-state job-finding rate	$\bar{p}(\theta)$	0.418	0.223
Steady-state job-filling rate	$\bar{q}(\theta)$	0.7	0.6
Steady-state total separation rate	$\bar{\rho}$	0.0316	0.0286
Steady-state endogenous separation rate	$\bar{\rho^n}$	0.0106	0.0096

and the data. Consumption and investment are strongly pro-cyclical while unemployment is strongly countercyclical in both cases. The model reproduces strong cross-country correlations for all variables, although most of it stems from the large cross-country correlation of shocks. Finally, the large persistence observed in the data is relatively well replicated by the model, especially for private consumption and unemployment. Appendix 1.7.3 presents the Impulse Response Functions resulting from technology shocks and provides more details on the transmission mechanisms that generate those second-order moments. Overall, the model reproduces most features of the European business cycle and is therefore a reliable representation of the economy of the Euro Area.

Table 1.2: Data-model comparison of the second moments of the main variables

Variable Z	σ_Z/σ_Y		$Corr(Z;Y)$		$Corr(Z_t;Z_{t-1})$		$Corr(Z;Z^*)$	
	Model	**Data**	**Model**	**Data**	**Model**	**Data**	**Model**	**Data**
Y	-	-	-	-	0.78	(0.89)	0.68	(0.9)
Y^*	-	-	-	-	0.84	(0.90)		
C	0.30	(0.57)	0.95	(0.82)	0.82	(0.84)	0.69	(0.74)
C^*	0.36	(0.93)	0.98	(0.95)	0.86	(0.89)		
I	4.42	(2.39)	0.96	(0.86)	0.74	(0.87)	0.53	(0.86)
I^*	4.60	(2.61)	0.96	(0.96)	0.83	(0.91)		
U	4.58	(4.52)	-0.90	(-0.68)	0.91	(0.91)	0.73	(0.64)
U^*	5.11	(5.18)	-0.91	(-0.94)	0.92	(0.93)		

1.5 Labor-market convergence in the Euro Area

The ultimate objective of this section is to investigate the steady-state and business cycle implications of labor-market convergence within the Euro Area. The government may directly change the level of unemployment benefits or the cost of firing a worker. It may also pass a law to redefine the role of unions, therefore altering the bargaining power of workers. Therefore, I simply imagine that a legislation making those three labor-market parameters identical in both countries is implemented in the Euro Area. Implementing these changes in this DSGE model means that the Home and Foreign countries have a new steady state where the UI benefits, the firing costs and the bargaining power of workers are identical between countries while the values of the other labor-market variables are endogenously determined as an equilibrium result.

First, I look at a simple simulation exercise making one parameter converge at a time to better disentangle the different effects taking place when they converge towards the value they have in the flexible country. Second, I consider a joint convergence and compare welfare in each steady state for different after-convergence flexibility levels, computing structural and stabilization welfare gains. More precisely, stabilization welfare gains/losses stem from differences in the welfare losses from business cycles around the initial and final steady states. Both analyses suggest that the welfare gains from labor-market convergence are potentially important if countries converge to a more flexible labor market. Finally, I contrast the business cycle implications of the convergence experiment, looking at the transition process. I find that the main results remain mainly unchanged qualitatively in the long run. High welfare gains are achieved in the long run when countries converge to a more flexible labor market. A short-term mechanism even magnifies the range of after-convergence calibrations that bring welfare gains.

1.5.1 Single-parameter convergence

Using the calibration presented in the previous section, I run an exercise where the labor-market parameters that can be influenced by the government converge one at a time to their level in the Home (flexible) country. I assume that those parameters are the UI benefit level χ, the firing cost level F and the bargaining power of workers σ. In this exercise, I only consider a convergence of those parameters towards their values in the Home (flexible) country, as flexibilization is usually considered as the best practice. I compute the convergence paths using perfect-foresight non-linear simulations of the model and obtain a full transition path for each scenario/exercise. In particular, after convergence, the economy settles into a new steady state.[25]

A legislation that requires an harmonization of a labor-market parameter in the Euro Area would probably be implemented progressively. Therefore, I assume that the converging parameters evolve according to the following process:

$$\Lambda_t = (1-\rho_\Lambda)Z_t + \rho_\Lambda \Lambda_{t-1} \tag{1.54}$$

$$log(\Upsilon_t) = \Lambda_t log(\bar{\Upsilon}_I) + (1-\Lambda_t) log(\bar{\Upsilon}_F) \tag{1.55}$$

$$log(\Upsilon^*_t) = \Lambda_t log(\bar{\Upsilon}^*_I) + (1-\Lambda_t) log(\bar{\Upsilon}^*_F) \tag{1.56}$$

for $\Upsilon = \{\chi, F, \sigma\}$ and where $\bar{\Upsilon}_I$ and $\bar{\Upsilon}_F$ are respectively the initial and final steady-state levels of each converging parameter. At the end of period 0, Z_t switches from 1 to 0, which triggers the convergence process. The speed of the convergence is governed by ρ_Λ, the persistence of Λ_t. I assume that full convergence should be achieved over a period that corresponds to the actual length of a government term in the Euro Area – between three and four years. Therefore, I impose $\rho_\Lambda = 0.7$ so that 98% of the convergence is done after three years. Other labor-market variables are defined by equilibrium conditions and therefore adjust endogenously to their final steady-state values. I also track the effects of a simultaneous convergence of all parameters: the three parameters follow the transition process described above at the same time. Table 3.4 shows the new steady-state levels of unemployment, consumption, output, wage and terms of trade after each type of convergence.

A joint convergence of the three parameters to their levels in the Home (flexible) country has a strong positive long-term effect for the Flexible country (second column of Table 3.4). The steady-state unemployment level decreases by more than 25% while consumption, output and wages are respectively 3%, 7% and 4% higher in the new steady state. Labor-market

[25]The algorithm is taken from Dynare and based on a Newton-type algorithm that solves a set of non-linear equations at each period using the special structure of the Jacobian matrix. See Juillard (1996) for details about the algorithm.

flexibilization also improves the economic conditions in the Home country even though this country does not implement any reform, as a positive spillover effect appears: consumption, output and wage are higher and unemployment is lower in the new steady state. However, for the Home (flexible) country, the transition is costly as it takes more than 10 years for output and unemployment to exceed their initial levels.

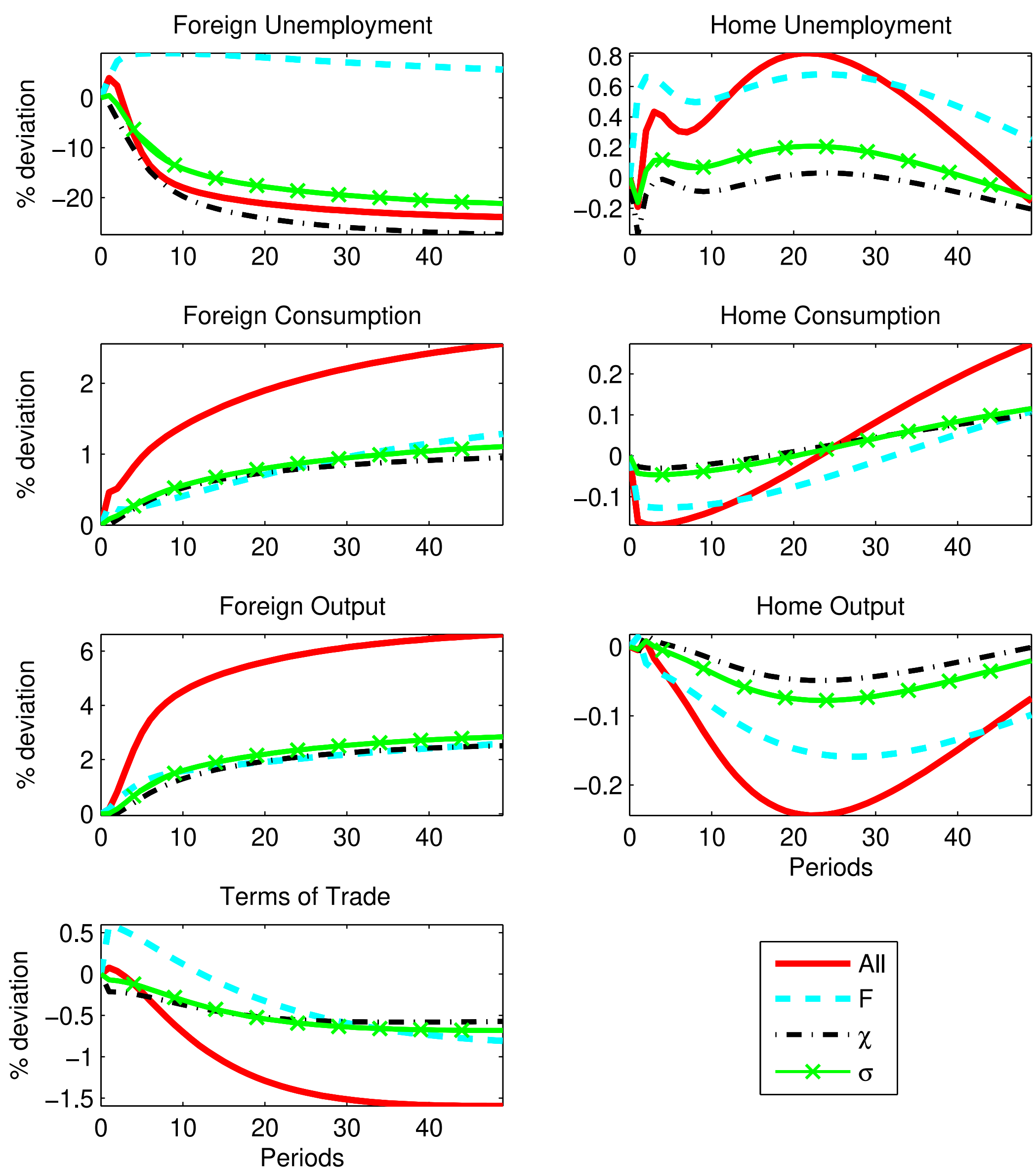
Table 1.3: Steady-state levels of key variables for different types of convergence

	Baseline	**All**	χ	**F**	σ
U	7.02%	-1.78%	-0.64%	-0.97%	-0.79%
U^*	11.37%	-25.41%	-28.50%	3.32%	-23.03%
C	0.618	0.42%	0.15%	0.23%	0.18%
C^*	0.588	3.21%	1.09%	1.92%	1.39%
Y	0.998	0.22%	0.08%	0.12%	0.10%
Y^*	0.923	7.20%	2.72%	3.23%	3.20%
w	0.572	0.08%	0.03%	0.05%	0.04%
w^*	0.556	3.86%	-0.71%	3.16%	0.27%
T	1.029	-1.46%	-0.53%	-0.80%	-0.65%

Baseline results are expressed per-capita, except for the unemployment rates that are expressed in percentages. Other results, in percentage, indicate variations with respect to the initial steady state. The convergence is implemented at the level of the parameters in the flexible country. "All" represents the simultaneous convergence of all three parameters.

A joint convergence of the three labor-market parameters mixes a large variety of effects, which may somehow blur the interpretation. Furthermore, the transition is a long-lasting process that may generate some negative short-term effects. Indeed, a joint convergence raises unemployment initially in the Foreign country before lowering it. A decomposition of the overall effects can be made by looking at the effects of letting parameters converge one at a time, to fully grasp the underlying adjustment mechanisms triggered by each one of them. Figure 1.1 reports the dynamics of unemployment, consumption, output and the terms of trade to the various convergence scenarios for 50 quarters.

Figure 1.1: Main variables' responses to different types of convergence



Results are expressed in percentage. The convergence is implemented at the level of the parameters in the flexible country. "All" represents the convergence of all four parameters.

First, a convergence of the level of the UI benefits χ to a lower value has large and positive effects for the Foreign country in the long run. Unemployment falls drastically, even more than when all three parameters convergence at the same time. However, as the wage is lower after the convergence, it leads to an increase of consumption and output that is only around 40% of their increase when all parameters converge. It also has a small positive effect for the Home country. In the model, the real wage is a weighted average of the marginal productivity of labor and the outside option of workers. On impact, the decrease of unemployment benefits generates a decrease of the outside option and therefore exerts downward pressures on the real wage of the Foreign (rigid) country. The latter is reduced by $(1-\sigma)\Delta\chi_t^*/P_{H,t}^*$. This causes a reduction of the marginal production cost, as well as a drop in the relative price of the Foreign good. This terms-of-trade effect generates an increase in the demand for the Foreign good in both countries through two effects: the income effect – the fall in the relative price of the Foreign good allows households of both countries to buy more of the two goods – and the substitution effect – the fall in the relative price of the Foreign good redirects demand towards this good. Foreign firms open new vacancies and increase hires to produce more to meet this additional demand. As such, unemployment strongly decreases. As the number of job-seekers diminishes, the wage slightly increases after a few periods but remains below its initial steady-state value. In the Home (flexible) country, the substitution effect generates a decrease of the demand for the Home good in the short term, pushing output to fall and leading to a small and short-lived increase in unemployment. Despite the income effect, consumption also slightly diminishes. After a few periods, the flexibilization of the labor market in the Foreign country generates enough income for the Foreign household to increase its consumption of the Home good. Home firms then hire new workers, unemployment decreases slowly while output and consumption increase. Overall, the adjustment process of unemployment, output and consumption is rather slow, as it respectively takes 30, 60 and 12 periods to fully reverse the negative short-term effect. In addition, in the Home (flexible) economy, the increase of consumption is stronger and quicker than the one of output because of the substitution effect.

Second, the convergence of the bargaining power of workers σ also leads to an increase of consumption and output. However, it is the only single-parameter convergence exercise that generates both an increase of the wage and a decrease of unemployment. A fall of the bargaining power of workers means that the share of the outside option in the bargained wage – *i.e.* the lower bound – decreases. Therefore, the wage first decreases, which generates a mechanism very similar to the convergence of the UI benefits: the relative price of the Foreign good decreases. The demand for the Foreign good rises, leading to a decrease of unemployment and an increase of output and consumption. However, in the case of a convergence in bargaining power, the outside option remains constant. As such, it is harder for firms to find new workers. Vacancies increase and the job-filling rate decreases. Therefore, after a few periods, the wage increases more, until it exceeds its initial steady-state level. As a consequence, unemployment decreases less than for a convergence of the unemployment benefits. For the Home (flexible) country, the transmission also goes through the dynamics of the terms of trade but it is quite stronger: consumption and output decrease more in the short run while the induced increase in unemployment is higher. In the long run, the income effect triggered by the dynamics of terms of trade overturns the substitution effect, and the final positive spillover effect is also slightly higher than in the case of converging UI benefits.

Third, a convergence of firing costs F brings a strong increase of consumption, output and wage in the long run for the Foreign (rigid) country. However, it also triggers a small increase in the rate of unemployment. Indeed, lowering the firing cost makes the cost of keeping low-profitability workers higher than the cost of firing them. This in turn leads to an increase of the separation rate and of the rate of unemployment in the short run. Nevertheless, as the real wage increases, consumption and output also rise from period 1. The real wage rise is driven by two indirect mechanisms. As low productivity workers are fired, the average productivity of continuing workers increases, which boosts wages. Besides, firms know – remember that simulations are conducted under perfect foresight – that the convergence process will drive the economy into a new steady state. As such, because they are forward looking, they change the price of their good immediately. This is costly due to the Rotemberg adjustment cost, and causes an increase of the marginal cost and therefore of the real wage. The latter mechanism was also present for the convergence of the other parameters (UI benefits and bargaining power) but was completely overturned by the other, more powerful, effects. This adjustment-cost effect vanishes in period 2. Associated with the increase in productivity, this generates a decrease of the terms of trade. Over time, the drop in the level of firing costs also increases job creations. As such, unemployment slowly diminishes from period 5 onwards. It boosts consumption and output. However, unemployment remains higher than in its initial steady-state. As previously, Home firms suffer from the terms-of-trade effect causing a rise in unemployment and a decrease of output and consumption. The income effect finally leads consumption and output to exceed their steady-state level but only after respectively 30 and 100 periods. Similarly, it is the convergence that requires the most time – more than 80 periods – for unemployment to go below its initial level in the Home (flexible) country.

The consequences of the simultaneous convergence of the three parameters is a mix of all those different effects. In the Foreign (rigid) country, the increase of the real wage in period 1 first dominates, generating a small rise of the unemployment level. However, the positive effects of labor-market flexibilization quickly overturn these negative effects, and unemployment falls below its initial value after only 3 quarters. The boost of productivity coming from the convergence of the firing cost and the decrease of wage due to the convergence of the bargaining power and of the unemployment benefits generate a decrease of the terms of trade from period 2 onwards. Hence, the demand for the Foreign good increases in both countries, requiring more hires. Unemployment decreases while output and consumption rise. Finally, as it gets harder to find job-seekers, the real wage also increases. This increase of output, consumption and real wage is much stronger than for any single-parameter convergence. However, it generates a lower reduction of rate of unemployment than when only the unemployment benefits converge. Spillovers to the Home (initially flexible) country are qualitatively similar under all scenarios. In the short term, consumption, output and the real wage decrease while unemployment increases. Those effects reverse in the longer run, when the income effect dominates. As such, a convergence of all three parameters brings a qualitatively similar dynamics but deliver quantitatively larger effects, as short-term losses and long-term gains are two to three times larger than for any single-parameter convergence.

1.5.2 Steady-state to steady-state welfare analysis

I now quantify the differences in terms of welfare between the steady-state where (all three) labor-market parameters are heterogeneous and the steady state where UI benefits, firing costs and the bargaining power of workers are homogeneous. Flexibilizing the labor market - *i.e.* here bringing labor-market parameters to their values in the Home country - is usually viewed as the best practice. Nevertheless, I study the consequences of a convergence of those three parameters to different levels of flexibility, and span the entire range of possible parameter values between the rigid case (all labor-market parameters of both countries converge to the values of these parameters in the Foreign country) and the flexible case (convergence to the values of the Home country). The analysis thus includes the whole set of politically implementable patterns of labor-market convergence, and allows to quantify the associated welfare gains/losses for both countries. I compute the steady state for each after-convergence calibration. In these new steady states, all the variables of the model are shifted and settle to new values endogenously but the transition path is ignored. Each convergence scenario is compared to the baseline steady state both in terms of the welfare losses from fluctuations they imply – stabilization welfare gains/losses being computed by simulating stochastic productivity shocks around the initial and the new steady state – and in terms of expected utility – structural welfare gains/losses. I track aggregate as well as country-level welfare gains/losses. More precisely, let

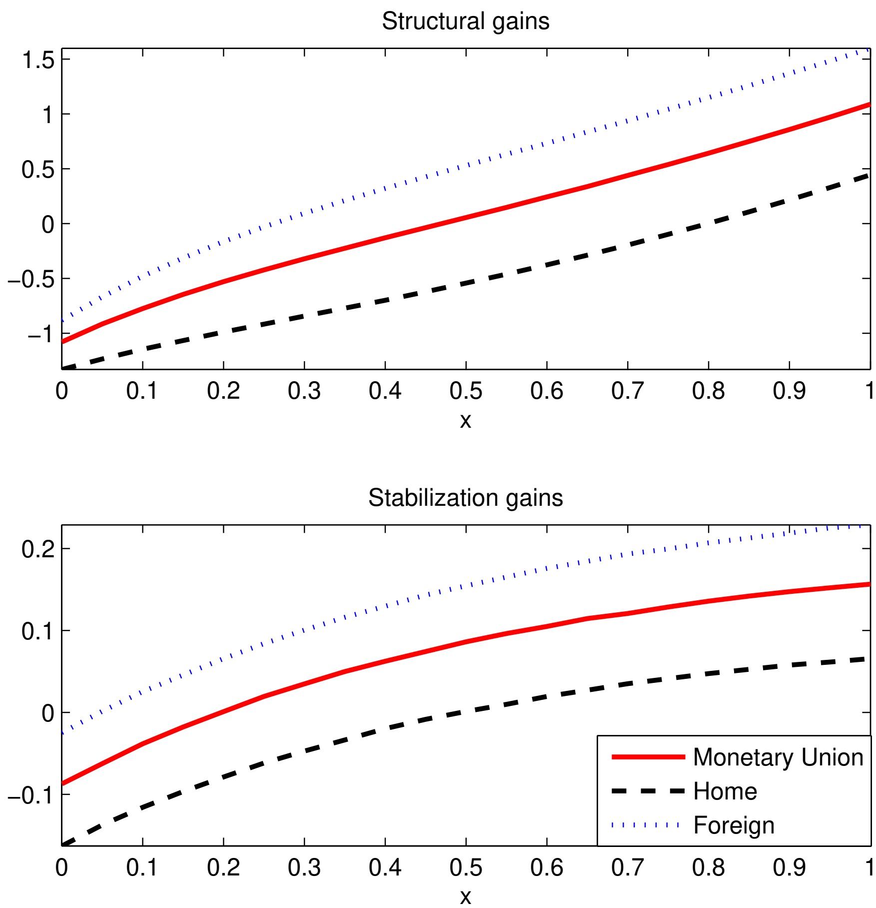
$$\begin{aligned}
\Omega_t^{MU} &= n\ u(C_t, U_t) + (1-n)\ u(C_t^*, U_t^*) + \beta\ \Omega_{t+1}^{MU} \\
\Omega_t &= u(C_t, U_t) + \beta\ \Omega_{t+1} \\
\Omega_t^* &= u(C_t^*, U_t^*) + \beta\ \Omega_{t+1}^*
\end{aligned}$$

respectively denote the Monetary Union, Home and Foreign welfare measures. The two types of welfare gains/losses, structural and stabilization, are respectively defined as:

$$\begin{aligned}
\Delta_{Str}^i &= \frac{\bar{\Omega}_F^i - \bar{\Omega}_I^i}{E_t(C_I^i)} \\
\Delta_{Sta}^i &= \frac{E_t(\Omega_F^i) - \bar{\Omega}_F^i - (E_t(\Omega_I^i) - \bar{\Omega}_I^i)}{E_t(C_I^i)}
\end{aligned}$$

for $i = \{MU, H, F\}$, where $E_t(C_I^{MU}) = nE_t(C_I) + (1-n)E_t(C_I^*)$. The subscripts F and I respectively stand for final and initial steady states. Structural welfare gains mean a higher utility at the new steady state. Stabilization welfare gains indicate smaller effects of second-order moments on expected utility. I make the three labor-market parameters converge at the same time. I define a parameter $x \in [0; 1]$ that indicates how close to the baseline calibration of the Home country (the one with a flexible labor market) those parameters are after the convergence: the higher x, the more flexible the labor market at the new steady state. Hence, a value of $x = 0$ means that the convergence is achieved towards the baseline calibration of the Foreign (rigid) country while a value of $x = 1$ indicates that the convergence is achieved towards the baseline calibration of the Home (flexible) country. A value of $x = 0.43$ implies a convergence at the size-weighted average of the baseline calibration. In general, for any x, $\Upsilon_C = \Upsilon_C^* = x \times \Upsilon_B + (1-x) \times \Upsilon_B^*$ for $\Upsilon = \{\chi, F, \sigma\}$. The complete results are reported in Figure 1.2 below. Table 1.4 complements Figure 1.2 and reports the structural and stabilization gains for a convergence towards the most rigid labor market ($x = 0$) and for a convergence towards the most flexible labor market ($x = 1$).

Figure 1.2: Steady-state welfare gains



Results are expressed in percentage of permanent per-capita consumption of the baseline calibration.

As indicated in Figure 1.2, the higher the value of x, the better the consequences in terms of structural welfare for the Home and the Foreign countries, and the Monetary Union as a whole. Furthermore, whatever the after-convergence labor-market flexibility, the welfare changes are more favorable to the Foreign (rigid) country than to the Home (flexible) country. The Foreign country gains in flexibility for any value of x except 0. As seen in the previous exercise, an increase of flexibility mainly boosts the competitiveness of Foreign goods. Indeed, production costs decrease for Foreign firms, which brings more demand for their products. Therefore, they hire more workers to increase their production, and Foreign output and consumption rise. Furthermore, the increase in separations induces a replacement of low productivity workers by higher productivity workers, leading to a rise in the average level of productivity, and a rise of wages that further fuels the rise in consumption. Therefore, the higher the flexibility (the higher x), the lower the unemployment rate and the higher consumption. As such, the Foreign country experiences structural welfare gains for a large range of after-convergence flexibility levels. Those gains can be as large as 1.6% of per-capita permanent consumption for $x = 1$. Only a low level of flexibility ($x < 0.27$) brings welfare losses for the Foreign country. This comes from two mechanisms. First, the direct positive effect is small as the level of flexibility is only slightly higher than in the baseline. Second, the labor market in the Home country becomes more rigid, which generates long-term negative spillover effects. For low values of x, these negative spillovers overturn the positive effects of labor-market flexibilization in the Foreign country. On the opposite, the Home country suffers from structural welfare losses for most calibrations, as its labor market becomes less flexible for any $x < 1$. Welfare losses reach 1.3% of per-capita consumption for $x = 0$, the most rigid convergence target. Nevertheless, it experiences structural welfare gains when x is higher than 0.8. In this case, the positive effects of the spillovers from flexibilization in the Foreign (rigid) country exceed the losses due to the loss in labor-market flexibility in the Home (flexible) country.

The positive spillover effects for $x = 1$ in the long run appear consistent with the results in Dao (2013) and Poilly and Sahuc (2013). In those papers, the result was rather expected, as they both assume complete financial markets. This modeling strategy means that a full insurance mechanism exists between families of both countries, leading to the international sharing of the newly generated wealth and efficiency gains. In my chapter, considering incomplete financial markets removes this insurance mechanism through the terms of trade – and the traditional risk-sharing condition. This leads to higher gains for the rigid country when it converges towards more flexible labor markets, and lower gains – from spillovers – for the flexible country. In spite of financial markets being incomplete, I show that a convergence of labor markets towards the most flexible country still brings structural welfare gains in the long term for both countries, which is arguably a key contribution of the chapter.

Finally, for the Monetary Union, welfare changes go from a loss of -1.08% of permanent consumption for $x = 0$ to a gain of 1.09% for $x = 1$. I find that any $x \in [0.47; 1]$ brings structural welfare gains, suggesting that such reforms would benefit the union as a whole even for modest degrees of flexibilization. However, a convergence towards the size-weighted average brings low structural welfare losses of 0.07% of permanent per-capita consumption.

Let the discussion now shift to the size of stabilization gains. Overall, a similar pattern emerges: the higher the flexibility level towards which convergence is achieved, the higher the stabilization gains. Having lower firing costs makes it easier for firms to smooth shocks. As such, the magnitude of movements in unemployment rates is dampened. Per-capita consumption depends directly on the relative number of employed individuals (paid the country's wage) to unemployed individuals (earning the country's UI benefits). Therefore, the volatility of consumption – and the negative effects of volatility on welfare – is the smallest when the unemployment volatility is the lowest, *i.e.* for $x = 1$. Although the magnitude of the stabilization gains is smaller, the range of calibrations that brings welfare gains is larger than for the structural welfare analysis. The Foreign country experiences small stabilization welfare losses only when for $x < 0.03$. The increase of the average unemployment level in the Monetary Union as a whole has negative stabilization welfare consequences for both countries. The Home country gains in term of stabilization welfare for more than half of the calibrations range ($x > 0.49$) and the Monetary Union as a whole for $x > 0.2$. This means that sizable stabilization welfare gains materialize at the size-weighted average. This shows the benefits of an homogenization of labor markets in a monetary union, as the monetary authority can choose a monetary policy that is more effective in stabilizing inflation fluctuations and the associated distortions for the union as a whole.

Table 1.4: Steady-state welfare analysis

	Structural welfare gains			**Stabilization welfare gains**		
	MU	**Home**	**Foreign**	**MU**	**Home**	**Foreign**
Rigid (x=0)	-1.080	1.330	-0.883	-0.087	-0.163	-0.025
Flexible (x=1)	1.088	0.445	1.599	0.157	0.066	0.229

Results are expressed in percentage of permanent per-capita consumption of the baseline calibration.

The above analysis, while providing many interesting results, remains limited along one important dimension: welfare numbers are computed in a static way, comparing steady state to steady state. However, if a reform fostering convergence on European labor markets was to be implemented, the path from heterogeneity to homogeneity could bring more complex welfare variations, especially in light of the different short-term and long-term effect exposed in Section 5.1. Indeed, this exercise revealed small negative short-term effects on consumption, output and unemployment in the Home (flexible) country and on unemployment in the Foreign (rigid) country. So, even though convergence brings theoretical welfare gains in the long run, i.e. when comparing steady states, studying the transition process is essential in assessing the desirability of an homogenization of the labor market from a welfare perspective, as well as its political feasibility.

1.5.3 Transitional welfare analysis

To determine the welfare consequences of the transition, I calculate the Hicksian-equivalent consumption change implied by the convergence process over 500 periods – or equivalently 125 years. The Hicksian-equivalent change measures during T periods the percentage of permanent per-capita consumption ξ_T that families would have to lose – or gain – to be indifferent between the situation where labor markets remain heterogeneous and the one where a legislation modifies labor markets until the firing costs, the UI benefits and the bargaining power of workers become homogeneous in the whole Euro Area:

$$E_0 \sum_{t=0}^{T} \beta^t \Big[u\big((1-\xi_T)C_t^i, U_t^i\big) \Big] = \sum_{t=0}^{T} \beta^t \Big[u(C_0^i, U_0^i) \Big] \tag{1.57}$$

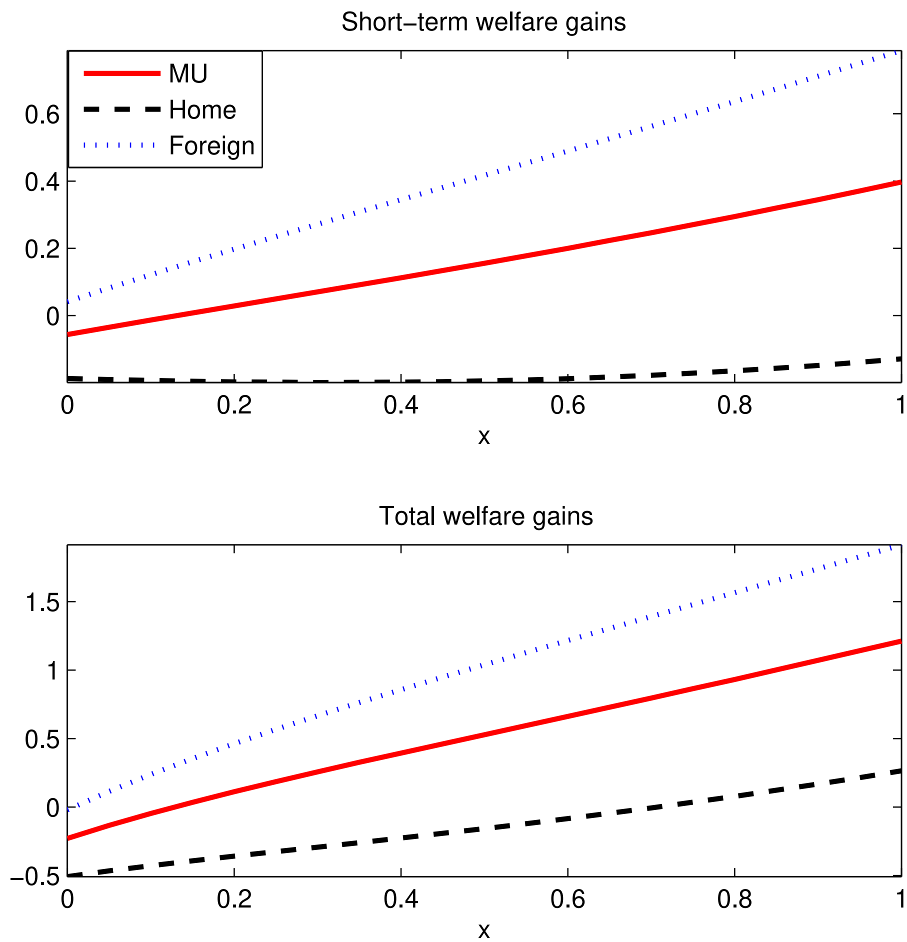
I compute this cumulative welfare changes over 500 periods for $x \in [0;1]$. I also report cumulative short-term variations of ξ_T, *i.e.* for a smaller T, as short-term losses tend to arise in transition processes, and as they are critical to assess the political economy of the reform. Following Cacciatore and Fiori (2016), I consider the short-term to last three years, as it is close to the duration of most public-office terms. I use perfect-foresight non-linear simulations of the model with the same transition process as in the first exercise. Again, the speed of convergence implies that 98% of the convergence is completed in three years (the persistence parameter ρ_Λ is equal to 0.7).[26] The other labor-market variables are defined by equilibrium conditions and therefore move to their final steady states as the three parameters adjust following the homogenization process. Figure 1.3 shows results of the transition process for $\rho_\Lambda = 0.7$ for the whole range of convergence calibrations.[27] It is completed by Table 1.5 that indicates short-term and total welfare gains for $x = 0$ and $x = 1$.

The transition analysis gives results that are consistent with the steady-state to steady-state study from a long-term perspective. The higher the after-convergence flexibility of the labor market, the higher the welfare gains. Furthermore, as expected, the Foreign (rigid) country benefits most from the convergence process. It also experiences welfare gains in the short run for any value of x. On the opposite, the Home country suffers from welfare losses in the short run whatever the after-convergence flexibility level and for most calibrations in

[26]The welfare results for $\rho_\Lambda = 0.99$ and $\rho_\Lambda = 0$ are detailed in Appendix 1.7.4 for comparison purposes.
[27]The precise changes of welfare over time are indicated for $x = 0$ and $x = 1$ in Appendix 1.7.5.

the long run.

Figure 1.3: Welfare gains after a transition



Results are expressed in percentage of permanent per-capita consumption of the baseline calibration.

As shown in the first exercise, a flexibilization of the labor market generates a small increase in the rate of unemployment in the short-term for the Foreign country. However, the increase of the real wage is large enough to compensate the potential negative effects on consumption. As such, consumption rises immediately and there are no short-term welfare losses for the Foreign country despite this small rise of unemployment. This positive short-term effect on the real wage actually boosts long-term welfare gains, as it helps overturning the negative spillover effect stemming from the loss of flexibility in the Home country. As such, The Foreign country only experiences long-term welfare losses when $x = 0$, that is when it keeps its baseline labor market, and welfare gains are up to 1.92% of per-capita permanent consumption for $x = 1$.

The Home (flexible) country experiences a short-term welfare loss whatever x. The loss of labor-market flexibility rapidly leads to a rise of the relative price of the Home good, which reduces the demand for this good and leads to a rise of unemployment and a decline of output and consumption. This movement in the relative price is exacerbated by the increase of labor-market flexibility in the Foreign country. In the long run, the income effect becomes larger and reverses these negative effects, implying positive spillover effects in the long run for the Home country, as for the previous exercises. The Home country experiences long-term welfare gains for $x > 0.71$.

The Monetary Union as a whole experiences welfare gains in the long run when the convergence is made at a flexible level and welfare losses when the convergence is implemented at a rigid level, as it was the case for the steady-state to steady-state analysis. Indeed, higher flexibility implies that consumption, output and the real wage are higher while unemployment is lower. Gains materialize for a very wide range, as the Monetary Union experiences welfare losses in the long-term only when $x < 0.13$. For the monetary union as a whole, the transmission mechanisms of a convergence process are not fundamentally altered in the short run, and short-term welfare gains arise for any $x > 0.15$. Thus, the reform has mostly positive effects both in the short and long terms, for the most rigid country and for the Monetary Union for a large set of convergence scenarios. It also has positive consequences for the most flexible country for high levels of after-convergence flexibility levels but only in the long run.

Table 1.5: Welfare analysis after a transition

	Short term welfare gains			**Total welfare gains**		
	MU	**Home**	**Foreign**	**MU**	**Home**	**Foreign**
Rigid (x=0)	-0.0565	-0.1869	-0.0202	-0.2289	-0.5075	-0.0202
Flexible (x=1)	0.3971	-0.1286	0.7882	1.2131	0.2642	1.9160

Results are expressed in percentage of permanent per-capita consumption of the baseline calibration. A positive number indicates a gain from a convergence of the labor markets.

1.6 Conclusion

In this chapter, I study the macroeconomic and welfare effects of labor-market convergences in the Euro Area. I use a DSGE model with two countries in a monetary union with Rotemberg adjustment costs, trade in consumption and investment goods, and search and matching frictions on the labor market. I look at the whole range of possible convergence scenarios between the actual calibration of the Home country (the flexible one) and of the Foreign country (the rigid one). I find that the after-convergence labor-market flexibility level is of paramount importance for the outcome. The higher the level of after-convergence flexibility, the higher the welfare gains from convergence. Comparing steady-state outcomes, an homogeneous labor market brings structural welfare gains for the Foreign country for a wide range of calibrations as its consumption, output and real wage increase and its unemployment level decreases. This also generates positive spillovers to the Home (flexible) inducing structural welfare gains for some convergence scenarios, despite the fact that the labor market becomes more rigid in this country. Stabilization welfare gains are experienced for both countries for a larger range of calibrations, as the common monetary policy becomes more effective in stabilizing the economies of more homogeneous countries. The Monetary Union also gains in terms of structural and stabilization welfare for a large fraction of the range of calibrations studied. Those results are indicative of the positive welfare impact of a labor-market convergence. The study of the full transition process shows similar long-term results, but gains are experienced for an even larger range of calibrations for both countries. Overall, those results suggest that a convergence of the labor markets should be carefully implemented to be beneficial to all countries of the EMU in the long term while dealing with possible short-term losses.

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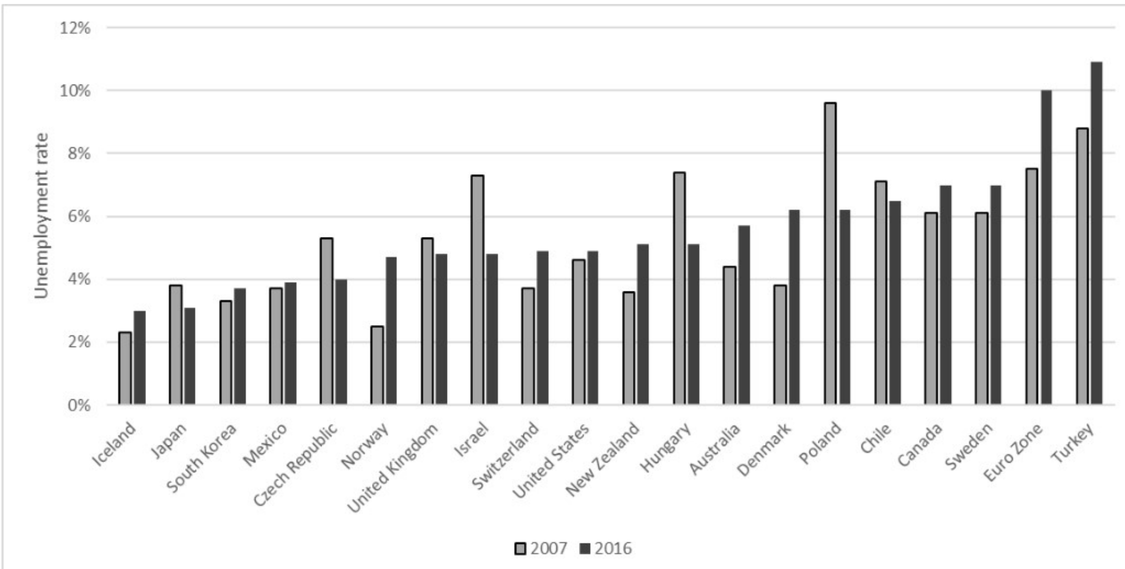
1.7 General Appendix

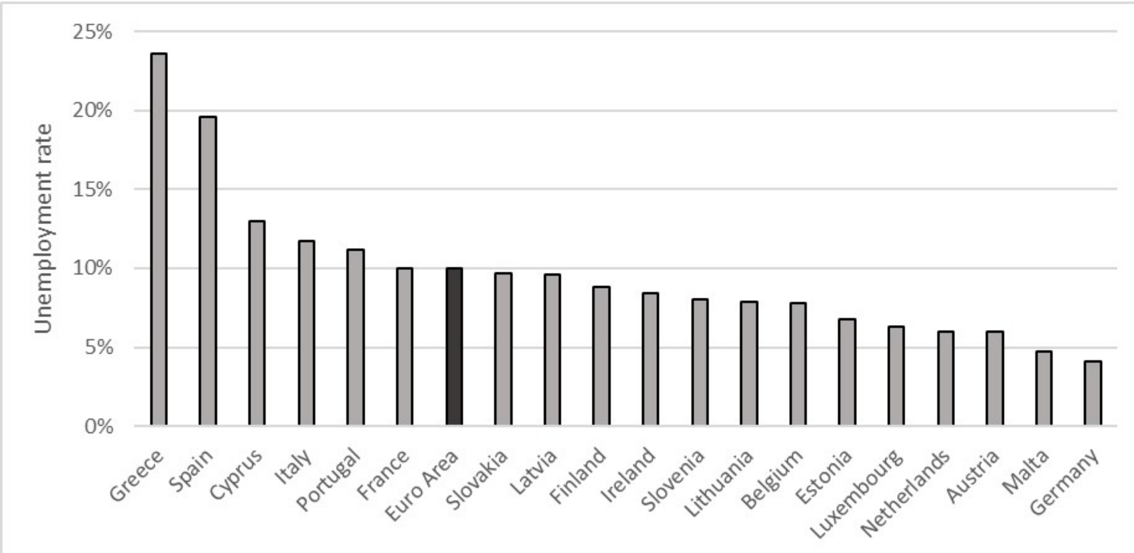
1.7.1 Unemployment rate by country

Figure 1.4: Unemployment rate in OECD countries



Harmonized unemployment rates from the OECD Labour market Statistics database

Figure 1.5: Unemployment rate in Eurozone countries in 2016



Unemployment rate from Eurostat Labour Force Survey adjusted series

1.7.2 Volatility decomposition

This model reproduces well the volatility of key variables especially of the unemployment rate. Therefore, it is of interest to understand what drives this volatility. Table 1.6 shows the absolute volatility of those key variables, for the data, the baseline model and for the same model but with certain parameters put equal to 0. This way, it is possible to know the role of a specific parameter to explain the volatility of the model. As we can see, no single parameter has a huge influence on the volatility of the model. Nevertheless, removing the firing costs decreases significantly the volatility of the unemployment rate as it improves the ability of firms to face economic shocks. On the contrary, forcing the endogenous separation rate to be equal to 0 increases the volatility of unemployment. This removes the possibility for firms to fire the less productive workers. As such, they will hire much less workers in hard times, increasing volatility of unemployment.

Table 1.6: Relative volatility in different models

Variable	Data	Baseline	$F = F^* = 0$	$h = h^* = 0$	$\rho^n = (\rho^n)^* = 0$	$\kappa_p = 0$
C	0.57	0.27	0.28	0.26	0.30	0.31
C^*	0.93	0.32	0.31	0.28	0.36	0.36
I	2.39	4.27	4.41	4.55	4.48	4.51
I^*	2.61	4.46	4.48	4.89	4.63	4.64
U	4.52	4.60	3.81	4.60	5.94	4.60
U^*	5.18	5.18	3.80	5.16	6.70	5.07

Results display relative volatilities with respect to the corresponding output (Y or Y^*).

1.7.3 Impulse Response Functions

Responses to local technology shocks. Figure 1.6 depicts local responses of key variables to the positive technology shocks in the Home country (solid line) and in the Foreign country (dashed line).[28] Notice that the cross-country correlation of shocks has been set to zero to disentangle the effects of a purely asymmetric shock. As usual in RBC models, the productivity shock raises wages and rental rates in period 2, but less than the rise in productivity, which makes marginal production costs fall. Firms can produce more with the same amount of inputs and expand production, raising the capital stock, vacancies and then hires. Local prices drop, therefore raising local and foreign demands for local varieties of goods, which is consistent with the increase in output. The family experiences a rise in its income through capital and labor, and uses it to smoothly rise its level of consumption. This consumption smoothing is achieved by raising investment in capital. Movements in quantities are greater in the periphery: the higher steady-state level of unemployment makes vacancies easier to fill after a positive productivity shock and therefore amplifies movements in employment. As a consequence, the response of most macroeconomic aggre-

[28] Results are given in percent deviation from the steady-state level.

gates (consumption in particular) are also amplified.

Responses to an external technology shock. Figure 1.7 presents the response of key variables to a technology shock hitting the other country of the Euro Area. In other words, Figure 1.7 shows the international transmission of productivity shocks. Here too, the shock is a purely asymmetric shock. An external productivity shock raises the relative price of the production good, which lowers the purchasing power of households and raises the price of production factors. As such, it increases the marginal production cost, leading inflation to jump. This raises the real interest rate, undermining consumption and causing an increase of the cost of capital and *in fine* a fall in investment. As the latter decreases, the stock of capital diminishes, forcing firms to hire more workers to maintain production. Therefore employment, vacancies (in the Foreign country) and wages are higher than their steady-state level during the first periods. However, wages increase less than the marginal cost and therefore less than prices. Therefore, the family decreases its consumption. As a consequence, output decreases which leads vacancies to fall and unemployment to go back to its steady-state level. As the effects of the shock fade, consumption ends up increasing, even exceeding its steady-state level. As the Foreign country is larger in size, when a positive technology shock occurs there, the Home country suffers from a larger fall in investment, capital and output. However, the size differential means that the negative consequences of the shock last for a shorter time when the shock spills over the Home country. Indeed, as the Foreign country is larger, it sells a higher quantity of goods in the Home country, leading to a quicker increase in consumption and investment for the Home country.

Figure 1.6: Impulse response functions after a local technology shock

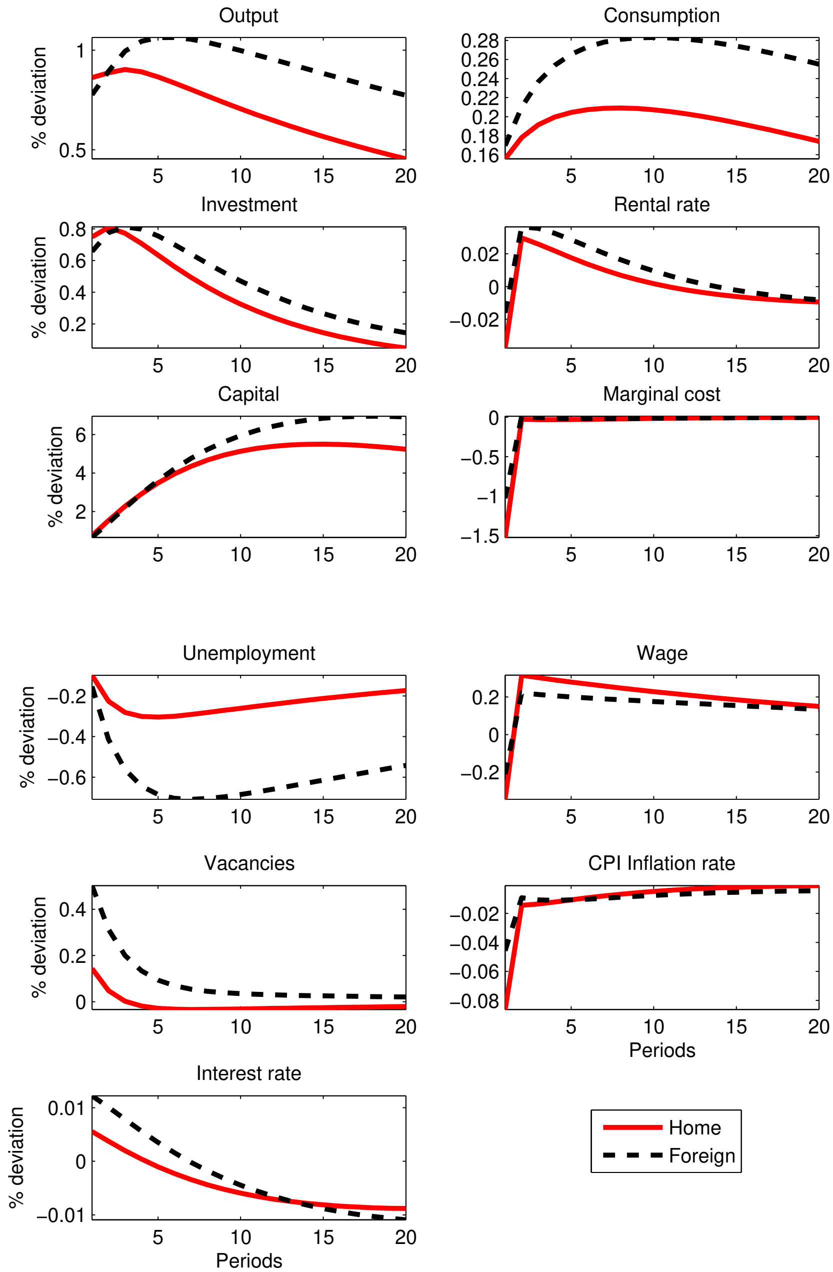
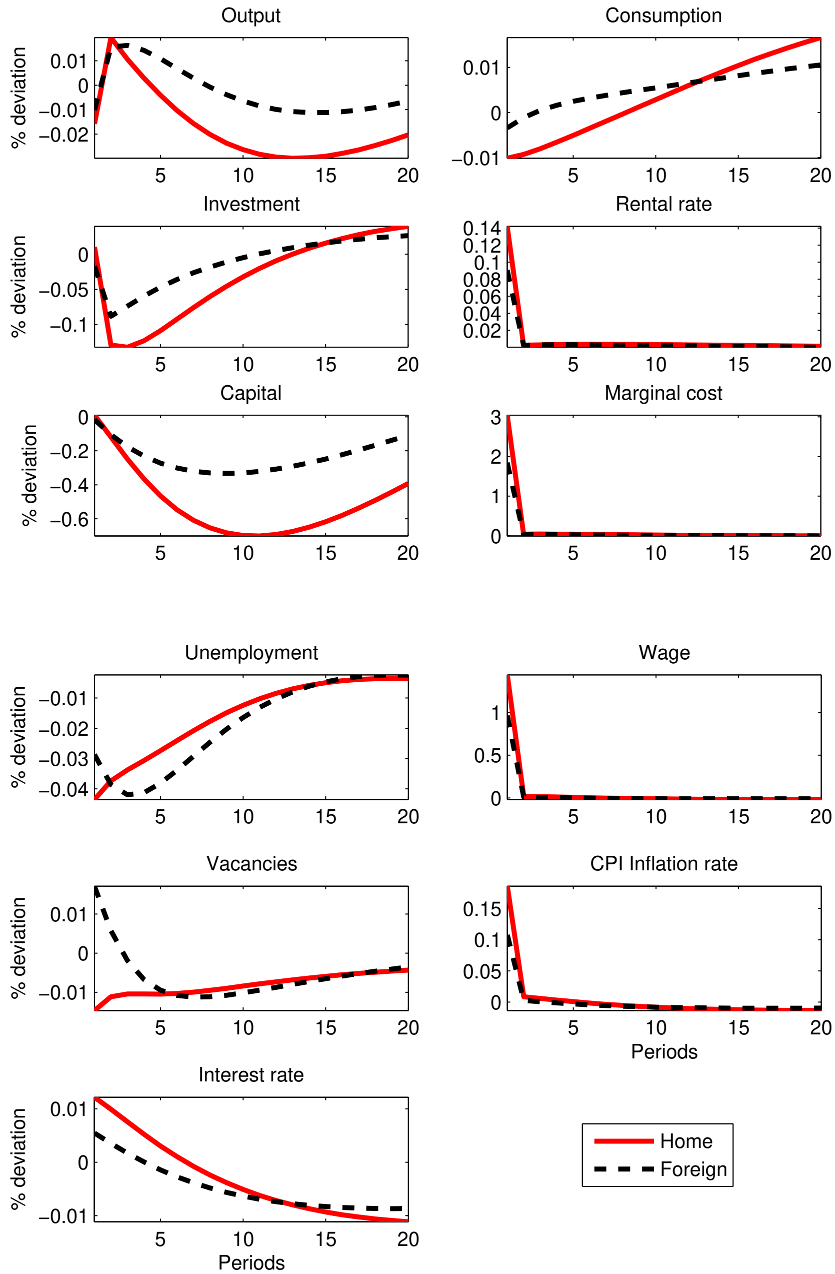


Figure 1.7: Impulse response functions after an external technology shock



1.7.4 Sensitivity analyses

The speed of convergence

Table 1.7 shows results of the transition analysis for a convergence towards specific values of x, and for different speeds of convergence for comparison purposes. I look at a convergence towards a rigid calibration $x = 0$ and a flexible calibration $x = 1$. Besides $\rho_\Lambda = 0.7$, I display results for a very slow transition $\rho_\Lambda = 0.99$ and a quick transition $\rho_\Lambda = 0$. The table reveals that the speed of convergence has no qualitative impacts on the long term results. Differences between a convergence with $\rho_\Lambda = 0$ and $\rho_\Lambda = 0.7$ are very small, but results are somewhat different quantitatively speaking for a convergence with $\rho_\Lambda = 0.99$. For a convergence at $x = 0$, the quicker the transition (the lower ρ_Λ), the higher the welfare losses for the Home country. This is due to the fact that increasing the speed of transition means that the Home country loses flexibility quicker. As welfare losses are discounted over time, a stronger decrease of the flexibility of the labor market during the first periods leads to a greater fall of welfare. On the contrary, for a convergence at $x = 1$, the Foreign country gains more in terms of welfare when the transition is quicker as the flexibilization of its labor market is more rapid. Again, this is due to the discounting of welfare losses over time. When the convergence is made at the rigid level, the long-term welfare effect for the Foreign country is very low as changes concerning its labor market in the long run are null. Therefore, changing the speed of convergence has very little impact in terms of welfare. The same happens for the Home country with a convergence at a flexible level. Since the long-term impact on welfare is very small, modifying the speed of convergence has little effect.

The Monetary Union as a whole loses more in terms of welfare in the rigid case when ρ_Λ is lower. Indeed, an increase of the speed of convergence has little effect on the Foreign country but raises losses for the Home country. The opposite mechanism occurs for a convergence towards the flexible level. Increasing the speed of transition leads to higher welfare gains for the Foreign country and little changes for the Home country. Therefore, welfare gains are higher for the Monetary Union when the speed of convergence is higher.

Table 1.7: Welfare gains for different speeds of convergence

	Monetary Union			
	Rigid (x=0)		**Flexible (x=1)**	
ρ_Λ	**ST**	**Total**	**ST**	**Total**
0.99	-0.015	-0.140	0.078	0.690
0.70	-0.057	-0.229	0.397	1.213
0	-0.058	-0.231	0.471	1.241
	Home country			
	Rigid (x=0)		**Flexible (x=1)**	
ρ_Λ	**ST**	**Total**	**ST**	**Total**
0.99	-0.073	-0.307	-0.063	0.166
0.70	-0.187	-0.508	-0.129	0.264
0	-0.184	-0.510	-0.131	0.265
	Foreign country			
	Rigid (x=0)		**Flexible (x=1)**	
ρ_Λ	**ST**	**Total**	**ST**	**Total**
0.99	0.029	-0.014	0.183	1.080
0.70	0.041	-0.020	0.788	1.916
0	0.036	-0.021	0.919	1.964

Results are given in percentage of permanent consumption. A positive number indicates a gain from a convergence of labor markets. ST stands for short-term welfare gains.

The trade elasticity parameter

Table 1.8 shows results of the transition analysis for a convergence with different values of the trade elasticity parameter. I compare the results of the baseline calibration with the results when $\phi = 6$ and $\phi = 0.8$. The former value corresponds to a common value in the international trade literature. The latter means that the Home and the Foreign goods are complementary. As previously, I look at a convergence towards a rigid calibration ($x = 0$) and a flexible calibration ($x = 1$). We can see that the results are robust to the value of the trade elasticity parameter. However, it brings some small quantitative differences. A high ϕ means that when the relative price of a good decreases, a stronger substitution in favor of this good occurs. As a consequence, the income effect inside the union is stronger. Therefore, for the Monetary Union as a whole, the higher ϕ, the higher the welfare gains (or the lower the losses), whatever the after-convergence flexibility level.

Looking at the country level, a convergence at a high flexibility level ($x = 1$) generates stronger welfare gains for the Foreign (rigid) country and lower gains for the Home (flexible) country in the long run when ϕ is higher. This is simply due to the higher substitutability between the goods that leads households in both countries to increase (diminish) more their demand for the Foreign (Home) good. In the short-term, results are similar except when $\phi = 0.8$: losses are higher for the Home country than when $\phi = 2$. This comes from the lower income effect in the Monetary Union as a whole. When the convergence is implemented at a rigid level ($x = 0$), the stronger substitution induced by the higher trade elasticity also favors the Foreign country. It even experiences very small welfare gains in the long run when $\phi = 6$. However, the complementarity between goods that is generated when $\phi = 0.8$ leads to small losses both in the short and long term for the Foreign country. For the Home country, the higher ϕ, the higher the long-term gains as the income effect is stronger. However, in the short-term, as the substitution effect dominates, losses are bigger when the trade elasticity is high.

Table 1.8: Welfare gains for different trade elasticities

	Monetary Union			
	Rigid (x=0)		**Flexible (x=1)**	
ϕ	**ST**	**Total**	**ST**	**Total**
6	-0.045	-0.196	0.418	1.254
2	-0.057	-0.229	0.397	1.213
0.8	-0.080	-0.331	0.215	1.086
	Home country			
	Rigid (x=0)		**Flexible (x=1)**	
ϕ	**ST**	**Total**	**ST**	**Total**
6	-0.206	-0.469	-0.341	0.062
2	-0.187	-0.508	-0.129	0.264
0.8	-0.147	-0.536	-0.261	0.771
	Foreign country			
	Rigid (x=0)		**Flexible (x=1)**	
ϕ	**ST**	**Total**	**ST**	**Total**
6	0.075	0.008	0.980	2.132
2	0.041	-0.020	0.788	1.916
0.8	-0.030	-0.175	0.573	1.323

Results are given in percentage of permanent consumption. A positive number indicates a gain from a convergence of labor markets. ST stands for short-term welfare gains.

The Portfolio intermediate cost parameter

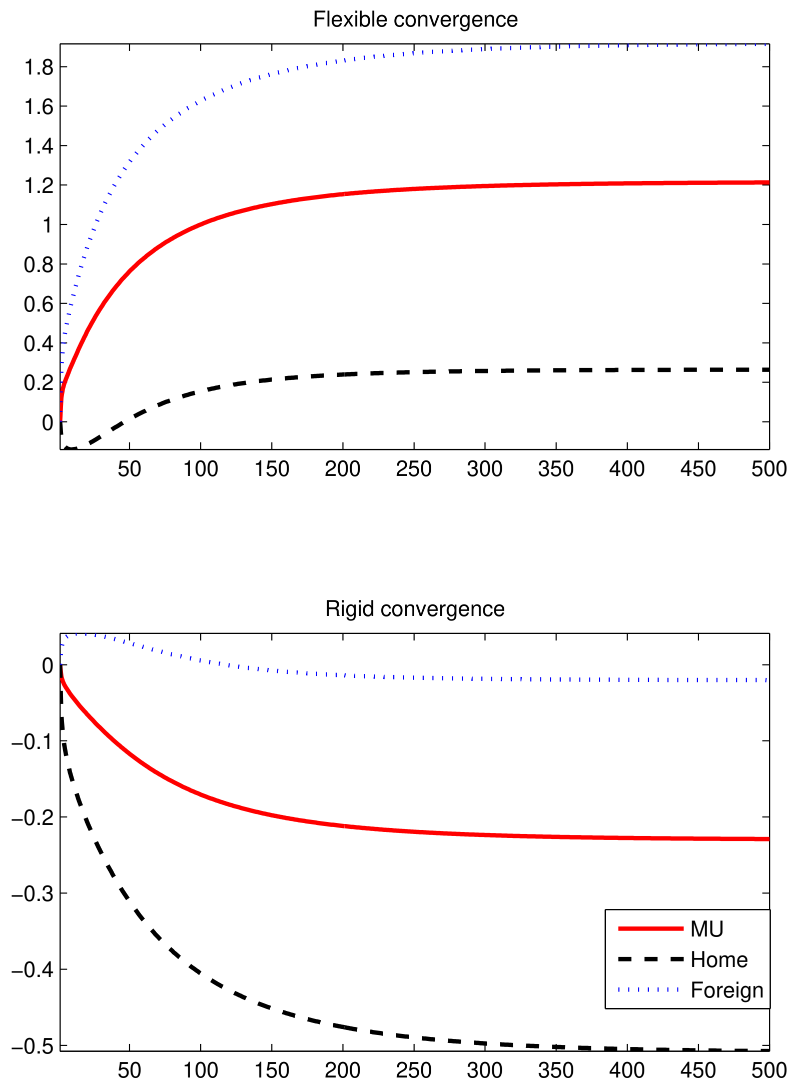
Table 1.9 shows the influence of the value of the portfolio intermediate cost parameter Γ on the welfare gains after a transition. I compare the welfare variations of the baseline model with the variations for a very high value of the portfolio intermediate cost parameter ($\Gamma = 0.01$) and a very low value ($\Gamma = 0.00001$). We can see that the value of this parameter has no repercussion for the Monetary Union as a whole whether in the short or the long term as it only modifies the way both countries share the new created wealth. Besides, in the long term, it does not reshape welfare variation for any country as $B_{MU} = B^*_{MU} = 0$ both at the initial and the final steady state. However, it has a small influence in the short run. The lower Γ, the higher welfare gains for the Foreign (rigid) country and the lower the gains for the Home (flexible) country. When the value of Γ is high, it means that the cost of being a net creditor on the international bond market increases. As such, when the convergence of the labor markets takes place and the Foreign country becomes net creditor, it must pay a higher portfolio intermediate cost to the Home country, lowering the welfare gains for the former country and increasing the gains for the latter in the short term.

Table 1.9: Welfare gains for different portfolio intermediate costs

	Monetary Union			
	Rigid (x=0)		**Flexible (x=1)**	
Γ	**ST**	**Total**	**ST**	**Total**
0.01	-0.057	-0.230	0.393	1.211
0.0007	-0.057	-0.229	0.397	1.213
0.00001	-0.056	-0.228	0.398	1.215
	Home country			
	Rigid (x=0)		**Flexible (x=1)**	
Γ	**ST**	**Total**	**ST**	**Total**
0.01	-0.155	-0.511	-0.031	0.249
0.0007	-0.187	-0.508	-0.129	0.264
0.00001	-0.217	-0.507	-0.212	0.271
	Foreign country			
	Rigid (x=0)		**Flexible (x=1)**	
Γ	**ST**	**Total**	**ST**	**Total**
0.01	0.016	-0.019	0.709	1.923
0.0007	0.041	-0.020	0.788	1.916
0.00001	0.065	-0.020	0.853	1.914

Results are given in percentage of permanent consumption. A positive number indicates a gain from a convergence of labor markets. ST stands for short-term welfare gains.

1.7.5 Cumulative transition welfare gains and losses



Results are expressed in percentage of permanent per-capita consumption of the baseline calibration.

1.8 Technical Appendix

1.8.1 Determination of the New Keynesian Phillips Curve

I start from the maximization problem linked to the dividends subject to the production function:

$$
\begin{aligned}
E_s \sum_{s=t}^{\infty} Q_{t+s} \Bigg\{ & \frac{P_{h,t+s}(i)}{P_{H,t+s}} Y_{t+s}(i) - \frac{R_{k,t+s}}{P_{H,t+s}} K_{t+s}(i) - \frac{W_{k,t+s}}{P_{H,t+s}} N_{t+s}(i) \\
& - \frac{\kappa_p}{2} \Big[\frac{P_{h,t+s}(i)}{P_{h,t+s-1}(i)} - 1 \Big]^2 Y_{t+s} - \kappa_v V_{t+s}(i) \\
& - MC_t \left[Y_{t+s}(i) - A_{t+s} a_{t+s} (K_{t+s}(i))^{\zeta} (N_{t+s}(i))^{1-\zeta} \right] \Bigg\}
\end{aligned} \tag{1.58}
$$

Using the equation $Y_t(i) = \left(\frac{P_{h,t}(i)}{P_{H,t}}\right)^{-\psi} Y_t$, I get

$$
\begin{aligned}
E_s \sum_{s=t}^{\infty} Q_{t+s} \Bigg\{ & \frac{P_{h,t+s}(i)}{P_{H,t+s}} \left(\frac{P_{h,t+s}(i)}{P_{H,t+s}} \right)^{-\psi} Y_{t+s} - \frac{R_{k,t+s}}{P_{H,t+s}} K_{t+s}(i) - \frac{W_{k,t+s}}{P_{H,t+s}} N_{t+s}(i) \\
& - \frac{\kappa_p}{2} \Big[\frac{P_{h,t+s}(i)}{P_{h,t+s-1}(i)} - 1 \Big]^2 Y_{t+s} - \kappa_v V_{t+s}(i) \\
& - MC_t \left[\left(\frac{P_{h,t+s}(i)}{P_{H,t+s}} \right)^{-\psi} Y_{t+s} - A_{t+s} a_{t+s} (K_{t+s}(i))^{\zeta} (N_{t+s}(i))^{1-\zeta} \right] \Bigg\}
\end{aligned} \tag{1.59}
$$

Deriving with respect to $P_{h,t}(i)$ leads to:

$$
\begin{aligned}
0 = & (1-\psi) \left(\frac{P_{h,t}(i)}{P_{H,t}} \right)^{-\psi} \frac{Y_t}{P_{H,t}} + \psi MC_t \left(\frac{P_{h,t}(i)}{P_{H,t}} \right)^{-\psi-1} \frac{Y_t}{P_{H,t}} \\
& - \kappa_p \Big[\frac{P_{h,t}(i)}{P_{h,t-1}(i)} - 1 \Big] \frac{Y_t}{P_{h,t-1}(i)} + E_t Q_t \kappa_p \Big[\frac{P_{h,t+1}(i)}{P_{h,t}(i)} - 1 \Big] \frac{Y_{t+1} P_{h,t+1}(i)}{P_{h,t}(i)^2}
\end{aligned} \tag{1.60}
$$

Each firm sets the same price in equilibrium: $P_{h,t}(i) = P_{H,t}$. Thus, we have:

$$(1-\psi)\frac{Y_t}{P_{H,t}} + \psi MC_t \frac{Y_t}{P_{H,t}} - \kappa_p \left[\pi_{H,t} - 1\right] \frac{Y_t}{P_{H,t-1}} + E_t Q_t \kappa_p \left[\pi_{H,t+1} - 1\right] \frac{Y_{t+1}}{P_{H,t}} \pi_{H,t+1} = 0 \quad (1.61)$$

Rearranging and simplifying, I finally obtain:

$$(1-\psi) + \psi MC_t + E_t Q_t \kappa_p (\pi_{H,t+1} - 1)\pi_{H,t+1} Y_{t+1}/Y_t = \kappa_p (\pi_{H,t} - 1)\pi_{H,t} \quad (1.62)$$

1.8.2 Determination of the wage of new workers

As it is common in the literature, the real wage is determined through a Nash-bargaining solution involving the maximization of total surplus. The latter is a geometric average of the surplus of workers and the one of firms, weighted by their relative bargaining power $\sigma \in [0;1]$:

$$w_t^N = arg\ max\ (\mathscr{W}_t^N - \mathscr{U}_t)^\sigma (\mathscr{J}_t^N)^{1-\sigma} \quad (1.63)$$

Using the definition of $\mathscr{W}_t^N$ and $\mathscr{J}_t^N$, the derivation gives:

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}(\mathscr{W}_t^N - \mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t^N)^{1-\sigma} - (1-\sigma)(\mathscr{J}_t^N)^{-\sigma}(\mathscr{W}_t^N - \mathscr{U}_t)^\sigma = 0 \quad (1.64)$$

It can be transformed into:

$$\frac{\sigma(1-\tau_t^W)P_{H,t}/P_t\big(\mathscr{W}_t^N - \mathscr{U}_t)^\sigma(\mathscr{J}_t^N)^{1-\sigma}}{(\mathscr{W}_t^N - \mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t^N)^{-\sigma}} = \frac{(1-\sigma)(\mathscr{J}_t^N)^{-\sigma}(\mathscr{W}_t^N - \mathscr{U}_t)^\sigma}{(\mathscr{W}_t^N - \mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t^N)^{-\sigma}} \quad (1.65)$$

which simplifies to

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\mathscr{J}_t^N = (1-\sigma)(\mathscr{W}_t^N - \mathscr{U}_t) \quad (1.66)$$

Then, we substitute for $\mathscr{W}_t^N$ and $\mathscr{J}_t^N$:

$$\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a^N - w_t^N \\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) - G(\underline{a}_{t+1}F\Big]\Bigg\} \\
&=(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t^N \\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) + \rho_{t+1}\mathscr{U}_{t+1}\Big] - \mathscr{U}_t\Bigg\}
\end{aligned} \tag{1.67}$$

Then, to simplify, we need to replace $\rho_{t+1}\mathscr{U}_{t+1}$ by $\rho^x\mathscr{U}_{t+1}+(1-\rho^x)F(a_t)\mathscr{U}_{t+1}$. Furthermore, we add and substract E_tQ_tF in the square brackets on the left side; and add and substract $E_tQ_t\mathscr{U}_{t+1}$ in the square brackets on the right side. It gives us:

$$\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a^N - w_t^N \\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) + (1-G(\underline{a}_{t+1})F\Big] - E_tQ_t(1-\rho^x)F\Bigg\} \\
&=(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t^N + E_tQ_t\mathscr{U}_{t+1} \\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) - \mathscr{U}_{t+1}(1-G(a_{t+1})\Big] - \mathscr{U}_t\Bigg\}
\end{aligned} \tag{1.68}$$

Now, let's transform Equation (1.66) to lead it one period and integrate it such that:

$$\sigma(1-\tau_{t+1}^W)\frac{P_{H,t+1}}{P_{t+1}}\int_{\underline{a}_{t+1}}^1(\mathscr{J}_{t+1}(a_{t+1})+F) = (1-\sigma)\int_{\underline{a}_{t+1}}^1(\mathscr{W}_{t+1}(a_{t+1})-\mathscr{U}_{t+1}) \tag{1.69}$$

we can obtain

$$
\begin{aligned}
&\sigma E_t Q_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) + (1-G(\underline{a}_{t+1})F\Big]\\
=&(1-\sigma)E_t Q_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^1 \mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) - \mathscr{U}_{t+1}(1-G(a_{t+1})
\end{aligned} \tag{1.70}
$$

Therefore we can use Equation (1.70) to simplify Equation (1.68):

$$
\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^\zeta N_t^{-\zeta}A_t a^N - w_t^N - E_t Q_t(1-\rho^x)F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t^N + E_t Q_t \mathscr{U}_{t+1} - \mathscr{U}_t\Bigg\}
\end{aligned} \tag{1.71}
$$

Then, we replace $\mathscr{U}_t$ by its expression to get:

$$
\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^\zeta N_t^{-\zeta}A_t a^N - w_t^N - E_t Q_t(1-\rho^x)F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t^N - \Big[(1-\tau_t^W)\frac{P_{H,t}}{P_t}\frac{\chi_t}{P_{H,t}} + h + E_t Q_t p(\theta_t)(\mathscr{W}_{t+1}^N - \mathscr{U}_{t+1})\Big]\Bigg\}
\end{aligned} \tag{1.72}
$$

Finally, we use the following triple equality:

$$
E_t Q_t(\mathscr{W}_{t+1}^N - \mathscr{U}_{t+1}) = \frac{\sigma}{1-\sigma}(1-\tau_t^W)\frac{P_{H,t}}{P_t}E_t Q_t \mathscr{J}_{t+1}^N = \frac{\sigma}{1-\sigma}(1-\tau_t^W)\frac{P_{H,t}}{P_t}\frac{\kappa}{q(\theta_t})} \tag{1.73}
$$

to get

$$
\begin{aligned}
&\sigma\Bigg\{[MC_t(1-\zeta)K_t^\zeta N_t^{-\zeta}A_t a^N - w_t^N - E_t Q_t(1-\rho^x)F\Bigg\}\\
=&(1-\sigma)\Bigg\{w_t^N - \Big[(1-\tau_t^W)\frac{\chi_t}{P_{H,t}} + \frac{P_t}{P_{H,t}}\frac{h}{1-\tau_t^W} + \frac{\sigma}{1-\sigma}\frac{p(\theta_t)}{q(\theta_t)}\kappa\Big]\Bigg\}
\end{aligned} \tag{1.74}
$$

We can easily simplify it to get the determination of the wage of new workers:

$$w_t^N = \sigma\Big[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a^N + \theta_t\kappa - E_tQ_t(1-\rho^x)F\Big] \\ + (1-\sigma)\Big(\frac{\chi_t}{P_{H,t}} + \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}}\Big) \tag{1.75}$$

1.8.3 Determination of the wage of old workers

The same process can be used to get to the determination of the wage of old workers. It is determined through the following Nash-bargaining process:

$$w_t(a_t) = arg\ max\ (\mathscr{W}_t(a_t) - \mathscr{U}_t)^{\sigma}(\mathscr{J}_t(a_t) + F)^{1-\sigma} \tag{1.76}$$

Using the definition of $\mathscr{W}_t(a_t)$ and $\mathscr{U}_t$, the derivation gives:

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t(a_t)+F)^{1-\sigma} - (1-\sigma)(\mathscr{J}_t(a_t)+F)^{-\sigma}(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma} = 0 \tag{1.77}$$

It can be transformed into

$$\frac{\sigma(1-\tau_t^W)P_{H,t}/P_t\big(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma}(\mathscr{J}_t(a_t)+F)^{1-\sigma}}{(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t(a_t)+F)^{-\sigma}} = \frac{(1-\sigma)(\mathscr{J}_t(a_t)+F)^{-\sigma}(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma}}{(\mathscr{W}_t(a_t)-\mathscr{U}_t)^{\sigma-1}(\mathscr{J}_t(a_t)+F)^{-\sigma}} \tag{1.78}$$

which we can simplify as

$$\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}(\mathscr{J}_t(a_t)+F) = (1-\sigma)(\mathscr{W}_t(a_t)-\mathscr{U}_t) \tag{1.79}$$

Then, we substitute for $\mathscr{W}_t(a_t)$ and $\mathscr{J}_t(a_t)$:

$$
\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t - w_t(a_t)\\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) - G(\underline{a}_{t+1}F\Big] + F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t(a_t)\\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) + \rho_{t+1}\mathscr{U}_{t+1}\Big] - \mathscr{U}_t\Bigg\}
\end{aligned}
\tag{1.80}
$$

Then, to simplify, we need to replace $\rho_{t+1}\mathscr{U}_{t+1}$ by $\rho^x\mathscr{U}_{t+1}+(1-\rho^x)F(a_t)\mathscr{U}_{t+1}$. Furthermore, we add and subtract E_tQ_tF in the square brackets on the left side; and add and subtract $E_tQ_t\mathscr{U}_{t+1}$ in the square brackets on the right side. It gives us:

$$
\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t - w_t(a_t) - E_tQ_t(1-\rho^x)F\\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1}) + (1-G(\underline{a}_{t+1})F\Big] + F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t(a_t) + E_tQ_t\mathscr{U}_{t+1}\\
&+E_tQ_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1}) - \mathscr{U}_{t+1}(1-G(a_{t+1})\Big] - \mathscr{U}_t\Bigg\}
\end{aligned}
\tag{1.81}
$$

Now, let's transform Equation (1.79) to leading it one period and integrating it such that

$$
\sigma(1-\tau_{t+1}^W)\frac{P_{H,t+1}}{P_{t+1}}\int_{\underline{a}_{t+1}}^{1}(\mathscr{J}_{t+1}(a_{t+1})+F) = (1-\sigma)\int_{\underline{a}_{t+1}}^{1}(\mathscr{W}_{t+1}(a_{t+1})-\mathscr{U}_{t+1}) \tag{1.82}
$$

we can obtain

$$\begin{aligned}
&\sigma E_t Q_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{J}_{t+1}(a_{t+1})dG(a_{t+1})+(1-G(\underline{a}_{t+1})F\Big]\\
=&(1-\sigma)E_t Q_t\Big[(1-\rho^x)\int_{\underline{a}_{t+1}}^{1}\mathscr{W}_{t+1}(a_{t+1})dG(a_{t+1})-\mathscr{U}_{t+1}(1-G(a_{t+1})
\end{aligned} \tag{1.83}$$

Therefore we can use Equation (1.83) to simplify Equation (1.81):

$$\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t-w_t(a_t)-E_tQ_t(1-\rho^x)F+F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t(a_t)+E_tQ_t\mathscr{U}_{t+1}-\mathscr{U}_t\Bigg\}
\end{aligned} \tag{1.84}$$

Then, we replace $\mathscr{U}_t$ by its expression to get:

$$\begin{aligned}
&\sigma(1-\tau_t^W)\frac{P_{H,t}}{P_t}\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t-w_t(a_t)-E_tQ_t(1-\rho^x)F+F\Bigg\}\\
=&(1-\sigma)\Bigg\{(1-\tau_t^W)\frac{P_{H,t}}{P_t}w_t(a_t)-\Big[(1-\tau_t^W)\frac{P_{H,t}}{P_t}\frac{\chi_t}{P_{H,t}}+h+E_tQ_tp(\theta_t)(\mathscr{W}_{t+1}^N-\mathscr{U}_{t+1})\Big]\Bigg\}
\end{aligned} \tag{1.85}$$

Finally, we use the following triple equality:

$$E_tQ_t(\mathscr{W}_{t+1}^N-\mathscr{U}_{t+1})=\frac{\sigma}{1-\sigma}(1-\tau_t^W)\frac{P_{H,t}}{P_t}E_tQ_t\mathscr{J}_{t+1}^N=\frac{\sigma}{1-\sigma}(1-\tau_t^W)\frac{P_{H,t}}{P_t}\frac{\kappa}{q(\theta_t)} \tag{1.86}$$

to get

$$\begin{aligned}
&\sigma\Bigg\{[MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t-w_t(a_t)-E_tQ_t(1-\rho^x)F+F\Bigg\}\\
=&(1-\sigma)\Bigg\{w_t(a_t)-\Big[(1-\tau_t^W)\frac{\chi_t}{P_{H,t}}+\frac{P_t}{P_{H,t}}\frac{h}{1-\tau_t^W}+\frac{\sigma}{1-\sigma}\frac{p(\theta_t)}{q(\theta_t)}\kappa\Big]\Bigg\}
\end{aligned} \tag{1.87}$$

We can easily simplify it to get the determination of the wage of old workers:

$$\begin{aligned} w_t(a_t) = \sigma\Big[& MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t a_t + \theta_t\kappa + (1 - E_tQ_t(1-\rho^x))F\Big] \\ & + (1-\sigma)\Big(\frac{\chi_t}{P_{H,t}} + \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}}\Big) \end{aligned} \tag{1.88}$$

1.8.4 Determination of the job creation condition

I start by substituting the expression of wages of new workers w_t^N into the expression of the value of a new filled job for firms $\mathscr{J}_t^N$:

$$\begin{aligned} \mathscr{J}_t^N = (1-\sigma)\Big[& (1-\zeta)MC_tA_ta^NK^{\zeta}N_t^{-\zeta} - \frac{\chi_t}{P_{H,t}} - \frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}} - E_tQ_t(1-\rho^x)F\Big] \\ & - \sigma\theta_t\kappa + E_tQ_t(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^1 \big(\mathscr{J}_{t+1}(a_{t+1}) + F\big)dG(a_{t+1})\Big] \end{aligned} \tag{1.89}$$

Then, using the fact that $\mathscr{J}_{t+1}(\underline{a}_{t+1}) + F = 0$, I can write:

$$\begin{aligned} \mathscr{J}_{t+1}^N &= \mathscr{J}_{t+1}^N - (\mathscr{J}_{t+1}(\underline{a}_{t+1}) + F) \\ &= (1-\sigma)\Big[(1-\zeta)MC_{t+1}K_{t+1}^{\zeta}N_t^{-\zeta}A_{t+1}(a^N - \underline{a}_{t+1}) - F\Big] \end{aligned} \tag{1.90}$$

Therefore, using the equality $\frac{\kappa}{q(\theta_t)} = E_tQ_t\mathscr{J}_{t+1}^N$, I obtain the job creation equation

$$\frac{\kappa}{q(\theta_t)} = (1-\sigma)E_tQ_t\Big[(1-\zeta)MC_{t+1}K_{t+1}^{\zeta}N_{t+1}^{-\zeta}A_{t+1}(a^N - \underline{a}_{t+1}) - F\Big] \tag{1.91}$$

1.8.5 Determination of the job destruction equation

I start by substituting the expression of wages of old workers $w_t(a_t)$ into the expression of the value of a old filled job for firms $\mathscr{J}_t(a_t)$:

$$\begin{aligned}\mathscr{J}_t(a_t)+F=(1-\sigma)\Big[(1-\zeta)MC_tA_ta_tK^{\zeta}N_t^{-\zeta}-\frac{\chi_t}{P_{H,t}}-\frac{h_t}{1-\tau_t^W}\frac{P_t}{P_{H,t}}+(1-E_tQ_t(1-\rho^x)F\Big]\\-\sigma\theta_t\kappa+E_tQ_t(1-\rho^x)\Big[\int_{\underline{a}_{t+1}}^{1}\big(\mathscr{J}_{t+1}(a_{t+1})+F\big)dG(a_{t+1})\Big]\end{aligned} \tag{1.92}$$

Then, using the fact that $\mathscr{J}_{t+1}(\underline{a}_{t+1})+F=0$, I can write:

$$\begin{aligned}\mathscr{J}_{t+1}(a_{t+1})+F&=\mathscr{J}_{t+1}(a_{t+1})+F-(\mathscr{J}_{t+1}(\underline{a}_{t+1})+F)\\&=(1-\sigma)(1-\zeta)MC_{t+1}K_{t+1}^{\zeta}N_{t+1}^{-\zeta}A_{t+1}(a_{t+1}-\underline{a}_{t+1})\end{aligned} \tag{1.93}$$

Finally, I replace $\mathscr{J}()$ by its expression in Equation (1.93) to obtain the job destruction condition:

$$\begin{aligned}MC_t(1-\zeta)K_t^{\zeta}N_t^{-\zeta}A_t\underline{a}_t+(1-E_tQ_t(1-\rho^x))F-\frac{\chi_t}{P_{H,t}}-\frac{P_t}{P_{H,t}}\frac{h_t}{1-\tau_t^W}-\frac{\sigma}{1-\sigma}\theta_t\kappa\\+E_tQ_t(1-\rho^x)MC_{t+1}(1-\zeta)K_{t+1}^{\zeta}N_{t+1}^{-\zeta}A_{t+1}\int_{\underline{a}_{t+1}}^{1}(a_{t+1}-\underline{a}_{t+1})dG(a_{t+1})=0\end{aligned} \tag{1.94}$$

Chapter 2

Automation, Offshoring and Employment Distribution in Western Europe

Abstract

This chapter investigates the effects of automation and offshoring on the dynamics of the occupational distribution of employment with a focus on Western Europe between 2000 and 2016. I use a general equilibrium model with three regions, three types of workers, ICT capital, trade in final goods and endogenous offshoring. Fed with exogenous measures of ICT-capital prices and trade costs, the model replicates key features of the data. It matches the observed dynamics of offshoring to Eastern Europe and Asian countries. It also reproduces accurately the observed polarization of the labor market: abstract and manual labor increase while routine labor falls. A counterfactual experiment reveals that automation is the main driver of the polarization. Since it is also the only factor that drives individuals to become abstract (high-skill) workers, it is welfare enhancing. The effects of falling trade costs on labor polarization are smaller, but imply welfare gains.

2.1 Introduction

Since the 18th century, machines and trade have modified the occupational distribution of employment. With the Industrial Revolution, small workshops with low-productivity skilled craftsmen were replaced by large factories with machines operated by low-skill workers. Those changes brought fear of a strong and permanent increase in unemployment. For example, in England, high-skill textile workers started the Luddite movement at the beginning of the 19th century to protest against the excessive use of machines since they believed it would impoverish them. However, the increase in unemployment was only temporary. New jobs were created: supervisors to look after workers or mechanics to fix machines. Besides, this new labor organization led to a strong decrease in the cost of English textile. As such, the international demand for English textile strongly increased at the expense of Indian handcraft production. Thus, overall labor demand did not decrease at that time in England. However, it brought a disruption of the labor-market as several occupations disappeared while others were created (see Mokyr, Vickers, and Ziebarth (2015)). More technological progress occurred later, during the 20th century, with the inception of electricity or electronic goods for instance. Furthermore, trade strongly increased with the invention of planes, improvement of boats or the decrease in tariffs with the General Agreement on Tariffs and Trade after World War II. Arguably, they all had similar consequences on employment. Automation and trade mainly had short-term temporary effects on the aggregate demand for labor, but led to long-term structural changes regarding the types of skills that are required and the precise tasks that must be performed.

This chapter investigates the respective effects of automation, and international trade on the occupational displacement of employment in Western Europe since 2000.[1] Over the recent period, automation has risen with the development of the Internet. Besides, Western European countries have increased their trade intensity after China joined WTO in 2001 or

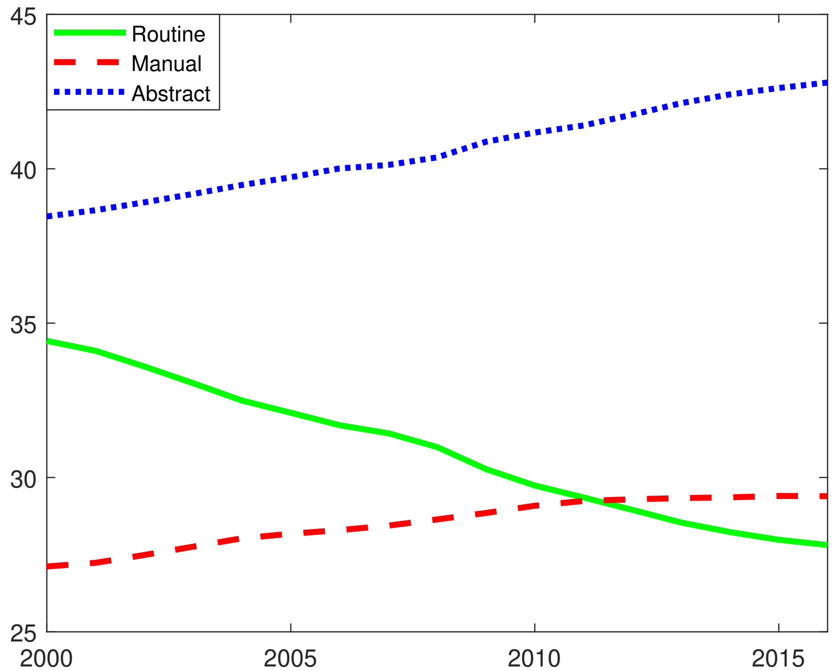
[1]From now on, when I use the notions of international trade or trade, it includes both offshoring and international trade on final goods.

after Central and Eastern European countries entered the European Union in 2004 and 2007. Both automation and trade – through offshoring – have been argued to drive the polarization of employment observed since the end of the 20th century in the United States (see Autor, Levy, and Murnane (2003), Autor and Dorn (2013), Acemoglu and Autor (2011)) and in Western European countries (see Goos, Manning, and Salomons (2014)). Polarization can be defined as the joint increase in the number of high-skill workers – supplying abstract tasks – and of low-skill workers – delivering manual non-routine tasks – at the expense of middle-skill workers supplying routine tasks. Automation and trade contribute to this polarization as routine occupations can be easily performed by machines or offshored to be supplied by workers in other countries. Figure 2.1 depicts the actual labor-market polarization process for Western European countries between 2000 and 2016. We can see that the routine labor share of the non-agricultural labor force dropped by 6.6 percentage points while the abstract and routine labor shares respectively increased by 4.3 and 2.3 percentage points during the period.[2]

I develop a three-region general equilibrium model with three types of workers. High-skill workers supply abstract labor and middle-skill workers provide routine labor to produce an internationally tradable good with Information and Communication Technology (ICT) capital. Low-skill workers supply manual labor to produce a non-tradable good. Individuals have to train to become either high or middle-skill workers but skills are randomly destroyed every period. Firms in Western European countries can offshore the production of routine tasks either to Central and Eastern European countries or to developing Asian countries. The amount of offshored labor depends on the relative wage and two costs: the trade cost and an "offshorability" cost that varies depending on the task. Furthermore, I follow the literature and assume that ICT capital and abstract labor are relative complements while ICT capital and routine labor are relative substitutes. The steady state of the model is carefully parametrized to replicate key characteristics of each of the three regions in 2000. I

[2]The separation of occupations between the three categories is explained in Appendix 2.7.1.

Figure 2.1: Occupational changes in Western Europe



Shares are expressed in percentages of all workers but Armed Forces (ISCO classification 0) and Agricultural workers (6 and 92.). The countries included are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

then subject the model to actual yearly exogenous processes for trade costs and ICT-capital prices. The model replicates accurately the increase in offshoring and the polarization of employment in Western European countries over the period. Using this reference path, I then conduct a counterfactual analysis where I feed the model with the exogenous processes separately to decompose the various factors explaining the dynamics of the occupational distribution of employment. Last, I look at the aggregate welfare consequences of those dynamics for Western Europe.

To begin with, the relevance of the model is validated by its ability to match almost perfectly the dynamics of offshoring for Western European firms. Moreover, the two driving forces replicate the job polarization process very well: the routine labor share falls from 34.4% to 28.4% of the non-agricultural labor share in the model while it drops from 34.4% to 27.8% in the data. The abstract labor share rises from 38.5% to 42.2% in the model while it reaches 42.8% in the data. The manual labor share increases from 27.1% to 29.4% both in the model and the data. The mechanisms run as follows. First, the decrease in the price of ICT capital leads to an increase in investment in ICT capital and thus of automation. It substitutes for routine labor. Workers losing their routine skills are not replaced and manual labor increases. Besides, as ICT capital and abstract labor are complementary, more people train to become high-skill workers and abstract labor rises. Second, the fall in trade costs causes an increase in international trade. In particular, with offshoring, Western European workers supplying routine labor are replaced by Central and Eastern European or Asian workers. As such, it also causes a decrease in routine labor and an increase in manual labor. However, offshoring has no direct consequence on the share of abstract labor. Hence, in the model, only automation has an up-skilling effect, meaning that it drives workers to become high-skill.

Furthermore, I find that the dynamics of the occupational employment distribution are mainly driven by automation. The increase in international trade has no effect on the abstract labor share while it explains only 18% of the decrease in the routine labor share and 43% of the increase in the manual labor share implied by the model. I also show that the impact of trade costs is entirely driven by offshoring. As international trade on final good remains relatively low in proportion of GDP, it barely affects the distribution of employment. Those results presenting automation as the main factor to explain job polarization are consistent with several recent studies focusing on Western European countries (Michaels, Natraj, and Van Reenen (2014) or Goos, Manning, and Salomons (2014)) but differ with the results of other papers looking at the United States as Cortes, Jaimovich, and H. E. Siu (2017) or Eden and Gaggl (2018).

Finally, the cumulative welfare analysis suggests that Western Europe experienced aggregate welfare gains during the period. Computing the Hicksian-equivalent consumption change between 2000 and 2016, the falls in ICT-capital price and trade costs are associated with an increase of almost 2.5% in consumption in Western European countries. International trade causes small but positive welfare gains. Indeed, the fall in trade costs leads to a decrease in the price of tradable goods, allowing individuals to increase consumption. However, 74% of the total welfare gains arise from automation, as it is the sole driver of the increase in the number of high-skill workers. Importantly however, automation has negative welfare effects in the short term. This comes from the fact that consumption and investment must first decrease to pay for the high-skill training of a higher number of individuals. Only after a few periods, per-capita consumption increases as more workers earn the (higher) abstract wage. As the utility is discounted over time, cumulative welfare becomes positive only in 2011 according to my simulations.

The chapter is organized as follows. Section 2 reviews the related literature and highlights the contributions of the chapter. Section 3 details the model. Section 4 presents the parametrization and the method to compute the exogenous driving forces. Section 5 exhibits the main results and confronts them to the data before running a counterfactual analysis and a welfare exercise. Section 6 concludes.

2.2 Related literature

The chapter relates to two strands of the literature on labor-market polarization: one that looks at the role of automation and one interested in the increase in international trade. Concerning automation, Autor, Levy, and Murnane (2003) develop a theory called the Routine-Biased Technical Change (RBTC). Looking at the data from the United States since 1960, they show that, as the cost of computer capital decreased, machines and computers have been replacing workers performing repetitive (routine) tasks. On the contrary, those machines are complementary with complex non-routine (abstract) tasks. As such, routine workers have been forced to train to be able to perform abstract tasks or have had to switch to manual non-routine tasks. As routine tasks are usually at the center of the wage spectrum, they show that this increase in automation has been a major reason for the polarization of employment and wages in the United States.

Following this seminal paper, several authors have conducted econometric analyses to investigate the relation between the increase in investment in machines and job polarization, including for European countries.[3] Among them are Michaels, Natraj, and Van Reenen (2014). Looking at ICT-investment data since 1980, they find a similar relation in the U.S. but also Japan and nine Western European countries. An increase in ICT investment has a positive correlation with the number of workers supplying abstract tasks and a negative one with the number of workers supplying routine labor. Goos, Manning, and Salomons (2014) focus on labor-market polarization in 16 Western European countries. Looking at data from 1993 to 2010, they find evidence of a decrease in jobs with a strong focus on routine tasks. Those jobs, in the middle of the wage spectrum, have seen their number decrease as they become supplied by machines or, more rarely, offshored. Senftleben-König, Wielandt, et al. (2014) and Dauth et al. (2017) find similar consequences of automation on employment polarization in Germany. Finally, using a decrease in taxes on ICT investment in the United Kingdom, Gaggl and Wright (2017) obtain a positive causal relation from ICT investment to employment and earnings of workers performing abstract tasks, and a negative causal relation to employment and earnings of workers performing routine tasks.

In addition to these empirical contributions, theoretical frameworks have been developed to try to formally explain the role of automation in job polarization. Acemoglu and Autor (2011) develop a task-based model to better reproduce this phenomenon than the

[3] See Jaimovich and H. Siu (2019) for a better view of the literature.

canonical model. Skills are endogenously allocated to tasks and new technology can replace middle-skill workers. This general framework notably explains the polarization of earnings with a particularly strong increase in the return on abstract skills. Autor and Dorn (2013) build a general equilibrium framework with similar characteristics and apply it to U.S. data. They show that automation is the central factor explaining the polarization of employment and earnings. Furthermore, they find that local labor markets that previously specialized in routine occupations saw a stronger decrease in routine labor and a higher rise in service occupations than other areas. Other models were later built by Lee and Shin (2017) or Bárány and Siegel (2018) for example to better explain some other aspects of job polarization.

Another strand of the literature looks at the role of the decrease in the costs of international trade, especially through offshoring, on labor-market polarization.[4] One of the first models was proposed by Feenstra and Hanson (1997). They build a framework with one country with a high-skill specialization (North) and a another with a low-skill specialization (South). They show that an increase in offshoring from the North to the South leads to a decrease in low-skill jobs in the North as they are transferred to the South. But, those new jobs are actually considered high skill in the South in comparison with pre-existing employment. As such, the share of relatively high-skill labor increases in each country. FDI data from the U.S. to Mexico supports their theoretical findings.

Other frameworks were later developed to better fit empirical patterns. Grossman and Rossi-Hansberg (2008) build a two-country model with asymmetric development and with high and low-skill workers. They show that an increase in offshoring to the South leads to the destruction of some low-skill jobs in the North, but that productivity gains arise, bringing an increase in the wage of both low and high-skill workers in the North. Ottaviano, Peri, and Wright (2013) modify the seminal model of Grossman and Rossi-Hansberg (2008)

[4] See Hummels, Munch, and Xiang (2018) for a literature review of the effects of international trade on occupational displacements.

to include several sectors and add low-skill immigration. They find that a reduction in offshoring costs associated with an increase in low-skill immigration lead natives to leave routine tasks for high-skill jobs. Nevertheless, the joint fall in offshoring costs and rise in immigration bring productivity gains, so that the number of native low-skill workers may remain similar or even increase. Eeckhout and Jovanovic (2012) build a sorting model where agents with two different levels of skill can be managers or workers. Productivity mostly depends on the skill level of the firm's manager. They find that economic integration leads to an increase in the share of managers and a decrease in the share of workers in high-income countries, as managers decide to hire workers from low-income countries. Mandelman (2016) develops a stochastic growth model with trade in tasks to investigate the small and medium term effects of a decrease in the cost of communication and transportation between countries. Feeding the model with different driving forces, he concludes that offshoring is the main factor explaining the decrease in middle-skill workers since the 1990s in the United States and the resulting job polarization.

Several papers have also studied the impact of international trade on employment and wage in Western European countries from an empirical point. Based on French data, Biscourp and Kramarz (2007) find evidence of a decrease in production jobs when firms increase their final good imports. Mion and Zhu (2013) observe a decrease in employment growth and an increase in skill upgrading for Belgian firms that decide to offshore parts of their production. They explain that the negative effect on employment is larger when offshoring to China. Looking at Germany, Baumgarten, Geishecker, and Görg (2013) show that, with the increase in offshoring, routine occupations suffer from a negative effect on wage and employment whether or not they are supplied by low-skill workers.

Only a few papers built theoretical frameworks to study the joint impact of offshoring and automation on the distribution of employment. Jung and Mercenier (2014) develop a two-sector general equilibrium model where skills are continuously distributed. Workers are sorted in tasks depending on their skills. As routine tasks get offshored or automated, workers previously supplying them either upgrade to cognitive tasks or downgrade to non-routine non-cognitive tasks. At the same time, through general equilibrium effects, wages increase at both ends of the wage distribution. They find one major difference between the effects of automation and offshoring. Offshoring decreases the number and the wage of workers performing routine tasks homogeneously. On the contrary, automation generates rising inequalities in employment and earnings within routine tasks. Cavenaile (2018) finds similar results by extending the model of Eeckhout and Jovanovic (2012). He includes four occupations and two sectors (service and goods) and adds automation. Only jobs in the goods sector can be offshored or automated. As such, an increase in offshoring or automation forces workers in the goods sector to either become managers if they are relatively high-skill or join the service sector as worker if they are relatively low-skill. This way, job polarization occurs. This paper also reproduces the increase in top income inequality. Finally, Mandelman and Zlate (2021) look at the respective roles of automation, low-skill migration and offshoring between high-income countries in explaining the changes in employment distribution in the United States since 1983. On the one hand, they find that automation and offshoring both decrease middle-skill employment, the latter having the strongest impact. On the other hand, low-skill migration decreases low-skill wages, pushing natives to train and become high-skill.

My chapter, by its purpose and modeling strategy, most closely relates to Mandelman and Zlate (2021). While my model tracks Mandelman and Zlate (2021) for the modeling of automation, it is closer to Ottaviano, Peri, and Wright (2013) for the offshoring part. In addition, Mandelman and Zlate (2021) use a theoretical framework and a calibration specifically built for the United States while my focus and parametrization are on Western European countries from 2000 to 2016. Besides, former papers do not take into account the consequences of trade on final goods. To the best of my knowledge, my chapter is the first to quantify the respective contributions of automation and trade to labor-market polarization in Western European countries using a dynamic general equilibrium framework.

2.3 Model

2.3.1 General presentation

The model features three regions representing old members of the European Union or Western European countries (EUR region); new members of the European Union or Central and Eastern European countries (CEE region); and the rest of the world represented by the main countries of South Asia (ROW region). Each region features three types of workers: high-skill workers who acquire the ability to supply abstract tasks through training, middle-skill workers who acquire the ability to supply routine tasks through training, and low-skill workers who supply manual non-routine tasks. Some high and middle-skill workers randomly lose their skills at every period. Manual labor is used to produce non-tradable goods while abstract and routine labor are combined with ICT capital to produce an internationally tradable good. For simplicity, I abstract from non-ICT capital as most of the increase in aggregate capital between 2000 and 2016 is due to ICT capital as its relative price has been falling rapidly over the period. Besides, ICT capital is of great interest when studying job polarization as most empirical studies find it to be complement with abstract labor but substitute with routine labor. For firms of the EUR region, routine tasks can be performed at home or offshored to any other region depending on their marginal cost. For firms of the CEE and ROW regions, all routine tasks are supplied domestically. Given my focus on structural change, I do not consider a government sector and assume financial autarky. In the next paragraphs, I present the details of the model from the perspective of the EUR region. When needed, variables for the CEE and ROW regions are presented respectively with C or R superscripts. As regions have different relative sizes, all variables are expressed per-capita. The functioning of the model is graphically presented in Appendix 2.7.3.

2.3.2 Households

In the EUR region, there is a large family made of a continuum of n individuals.[5] Although members are heterogeneous in terms of skills, family members are insured against income fluctuations: members pool their income to achieve the same level of individual consumption as in Merz (1995). Family members derive utility from consumption C_t. The family head thus maximizes the utility $u(C_t)$:

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} \ln(C_t) \tag{2.1}$$

subject to the budget constraint:

$$W_{m,t}N_t + \eta_t N_{r,t} + \pi_t N_{a,t} + R_{k,t}K_t + Div_t = P_t(C_t + I_t) + f_{Na,t}N_{Na,t} + f_{Nr,t}N_{Nr,t} \tag{2.2}$$

Sources of income are presented on the left-hand side while uses of this income are on the right-hand side. On the LHS, for the ease of analysis, I separated income due to the work effort from the premium due to supplying routine or abstract work. Total raw labor income is $W_{m,t}N_t$. This corresponds to a unit base wage $W_{m,t}$ multiplied by the number of workers N_t. Low-skill workers $N_{m,t}$ supply manual labor. They only receive the base wage $W_{m,t}$ for their production. Each worker supplying heterogeneous routine tasks $N_{r,t}$ earns a positive premium η_t over the base wage every period.[6] High-skill workers supplying abstract labor $N_{a,t}$ earn the base wage plus a premium π_t that comes from their training and that is higher than the routine premium. The family also earns a return $R_{k,t}$ per unit of ICT capital K_t. Finally, it shares the profit Div_t that is the sum of profits coming from the monopolistic firms producing the tradable good and those producing the non-tradable good. On the RHS, the family can consume the final good C_t or invest in the ICT-capital

[5] The CEE family counts n^C individuals and the ROW family $n^R = 1 - n - n^C$ individuals.

[6] Goos, Manning, and Salomons (2014) show that workers supplying manual tasks are at bottom of the wage distribution while workers supplying routine tasks are in the middle of the wage distribution.

good I_t at a unit price P_t. It also decides to train $N_{Na,t}$ individuals to become high-skill workers by paying the sunk cost $f_{Na,t}$. The latter cost is expressed in terms of raw labor: $f_{Na,t} = f_{Na} W_{m,t}$. Those workers become immediately productive to supply the abstract task. Each period, a share δ_a of high-skill workers sees their set of skills become obsolete and becomes low-skill workers. Similarly, the family decides to train $N_{Nr,t}$ new middle-skill workers who become immediately productive to supply routine tasks. To this end, the family pays the sunk cost $f_{Nr,t} = f_{Nr} W_{m,t}$. As for abstract workers, a share δ_r of middle-skill workers sees their set of skills become obsolete and becomes low-skill workers at each period. As such, the laws of motion for high-skill and middle-skill workers are respectively:

$$N_{a,t} = (1 - \delta_a) N_{a,t-1} + N_{Na,t} \tag{2.3}$$

$$N_{r,t} = (1 - \delta_r) N_{r,t-1} + N_{Nr,t} \tag{2.4}$$

Therefore, low-skill workers $N_{m,t}$ have the following law of motion:

$$N_{m,t} = N_{m,t-1} - N_{Na,t-1} - N_{Nr,t-1} + \delta_a N_{a,t-1} + \delta_r N_{r,t-1} \tag{2.5}$$

To sum up, the total number of workers N_t is the sum of high-skill workers supplying abstract labor $N_{a,t}$, middle-skill workers supplying routine labor $N_{r,t}$ and low-skill workers $N_{m,t}$

$$N_t = N_{a,t} + N_{r,t} + N_{m,t} \tag{2.6}$$

I normalize $N_t = 1$, meaning that each amount $N_{o,t}$ with $o = \{a, r, m, Na, Nr\}$ is actually the probability for a worker to be that specific type of worker.

The stock of ICT capital follows a law of motion with an exogenous perturbation $\epsilon_{K,t}$:

$$K_{t+1} = (1 - \delta_K) K_t + \epsilon_{K,t} I_t \tag{2.7}$$

with δ_K the depreciation rate of capital and $(\epsilon_{K,t})^{-1}$ the relative cost of ICT capital with respect to the price of consumption goods. First-order conditions with respect to C_t, K_{t+1}, I_t, $N_{a,t}$ and $N_{r,t}$ imply:

$$\lambda_t = \beta E_t \left\{ \frac{R_{K,t+1}}{P_{t+1}C_{t+1}} + \lambda_{t+1}(1-\delta_K) \right\} \tag{2.8}$$

$$\lambda_t = \frac{1}{\epsilon_{K,t}C_t} \tag{2.9}$$

$$f_{Na,t} = \pi_t + \beta E_t \left\{ (1-\delta_a)\frac{P_tC_t}{P_{t+1}C_{t+1}} f_{Na,t+1} \right\} \tag{2.10}$$

$$f_{Nr,t} = \eta_t + \beta E_t \left\{ (1-\delta_r)\frac{P_tC_t}{P_{t+1}C_{t+1}} f_{Nr,t+1} \right\} \tag{2.11}$$

where λ_t is the Lagrange multiplier associated with the law of motion of ICT capital. Equations (2.8) and (2.9) give the standard choices for capital and investment. Equations (2.10) and (2.11) show that the sunk cost of training must be equal to the expected discounted sum of premiums, taking into account that skills can become obsolete at each period.

Per-capita consumption and investment are defined as Armington aggregators of tradable and non-tradable goods:

$$\nu_t = \left[(\alpha_y)^{\frac{1}{\rho}} (\nu_{H,t})^{\frac{\rho-1}{\rho}} + (1-\alpha_y)^{\frac{1}{\rho}} (\nu_{N,t})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \tag{2.12}$$

with $\nu = \{C, I\}$. Variables $\nu_{H,t}$ and $\nu_{N,t}$ respectively stand for the quantities of tradable and non-tradable goods in the bundle and ρ is the elasticity of substitution between tradable and non-tradable goods. Tradable-good quantities $\nu_{H,t}$ are themselves a bundle:

$$\nu_{H,t} = \left[(1-\alpha_C-\alpha_R)^{\frac{1}{\phi}} (\nu_{T,t})^{\frac{\phi-1}{\phi}} + (\alpha_C)^{\frac{1}{\phi}} (\nu_{T,t}^C)^{\frac{\phi-1}{\phi}} + (\alpha_R)^{\frac{1}{\phi}} (\nu_{T,t}^R)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \tag{2.13}$$

where α_R and α_C respectively capture openness with the ROW and CEE regions. They both belong to the interval $[0, 1]$, and $\alpha_C + \alpha_R < 1$ captures the total degree of trade openness.

Variables $\nu_{T,t}$, $\nu^C_{T,t}$ and $\nu^R_{T,t}$ respectively denote the per-capita quantities of EUR, CEE and ROW varieties of tradable goods consumed in the EUR region. Parameter ϕ is the trade elasticity between those tradable goods. Variables $\nu_{N,t}$, $\nu_{T,t}$, $\nu^C_{T,t}$ and $\nu^R_{T,t}$ are themselves bundles of good varieties, respectively defined as:

$$\nu_{N,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\gamma_N}} \int_0^n \nu_{N,t}(i)^{\frac{\gamma_N-1}{\gamma_N}}\, di\right]^{\frac{\gamma_N}{\gamma_N-1}} \tag{2.14}$$

$$\nu_{T,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\gamma_T}} \int_0^n \nu_{T,t}(i)^{\frac{\gamma_T-1}{\gamma_T}}\, di\right]^{\frac{\gamma_T}{\gamma_T-1}} \tag{2.15}$$

$$\nu^C_{T,t} = \left[\left(\frac{1}{n^C}\right)^{\frac{1}{\gamma_T}} \int_0^{n^C} \nu^C_{T,t}(i)^{\frac{\gamma_T-1}{\gamma}}\, di\right]^{\frac{\gamma_T}{\gamma_T-1}} \tag{2.16}$$

$$\nu^R_{T,t} = \left[\left(\frac{1}{1-n-n^C}\right)^{\frac{1}{\gamma_T}} \int_{n+n^C}^1 \nu^R_{T,t}(i)^{\frac{\gamma_T-1}{\gamma_T}}\, di\right]^{\frac{\gamma_T}{\gamma_T-1}} \tag{2.17}$$

where γ_N and γ_T are the elasticities of substitution respectively for the non-tradable and the tradable varieties of goods. The aggregate price index is given by:

$$P_t = \left[\alpha_y (P_{H,t})^{1-\rho} + (1-\alpha_y)(P_{N,t})^{1-\rho}\right]^{\frac{1}{1-\rho}} \tag{2.18}$$

where $P_{N,t}$ is the price index of the non-tradable good and $P_{H,t}$ the consumer price index of tradable goods given by:[7]

$$P_{H,t} = \left[(1-\alpha_C-\alpha_R)(P_{T,t})^{1-\phi} + (\alpha_C)(\tau^C_t e^C_t P^C_{T,t})^{1-\phi} + (\alpha_R)(\tau^R_t e^R_t P^R_{T,t})^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{2.21}$$

where $P_{T,t}$, $P^C_{T,t}$ and $P^R_{T,t}$ denote the producer price indices of the tradable goods respectively

[7] The consumer price indices of tradable goods in the CEE region and the ROW region are respectively:

$$P^C_{H,t} = \left[(1-\alpha^C_E-\alpha^C_R)(P^C_{T,t})^{1-\phi} + (\alpha^C_E)(\tau^C_t 1/e^C_t P_{T,t})^{1-\phi} + (\alpha^C_R)(\tau^{CR}_t e^R_t/e^C_t P^R_{T,t})^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{2.19}$$

$$P^R_{H,t} = \left[(1-\alpha^R_C-\alpha^R_E)(P^R_{T,t})^{1-\phi} + (\alpha^R_C)(\tau^{CR}_t e^C_t/e^R_t P^C_{T,t})^{1-\phi} + (\alpha^R_E)(\tau^R_t 1/e^R_t P_{T,t})^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{2.20}$$

from EUR, CEE and ROW regions, e_t^O is the bilateral nominal exchange rate with region $O = \{C, R\}$ and $\tau_t^O = \tau^O \epsilon_{F,t}^O$ is an (exogenous and time-varying) iceberg cost paid to import or export a good with region $O = \{C, R\}$. This iceberg cost takes into account all types of costs to be paid when trading in another region such as trade barriers or transportation and administrative costs.[8]. The price indices are defined as:

$$P_{N,t} = \left[\left(\frac{1}{n}\right)\int_0^n P_{N,t}(i)^{1-\gamma_N} di\right]^{\frac{1}{1-\gamma_N}} \tag{2.22}$$

$$P_{T,t} = \left[\left(\frac{1}{n}\right)\int_0^n P_{T,t}(i)^{1-\gamma_T} di\right]^{\frac{1}{1-\gamma_T}} \tag{2.23}$$

$$P_{T,t}^C = \left[\left(\frac{1}{n^C}\right)\int_0^{n^C} P_{T,t}^C(i)^{1-\gamma_T} di\right]^{\frac{1}{1-\gamma_T}} \tag{2.24}$$

$$P_{T,t}^R = \left[\left(\frac{1}{1-n-n^C}\right)\int_{n+n^C}^1 P_{T,t}^R(i)^{1-\gamma_T} di\right]^{\frac{1}{1-\gamma_T}} \tag{2.25}$$

Optimization gives the following demand functions in the EUR region for variety i of the non-tradable good, the EUR-produced, CEE-produced and ROW-produced tradable goods respectively :

$$\nu_{N,t}(i) = \left(\frac{1-\alpha_y}{n}\right)\left(\frac{P_{N,t}(i)}{P_{N,t}}\right)^{-\gamma_N}\left(\frac{P_{N,t}}{P_t}\right)^{-\rho}(n\nu_t) \tag{2.26}$$

$$\nu_{T,t}(i) = \left(\frac{\alpha_y(1-\alpha_C-\alpha_R)}{n}\right)\left(\frac{P_{T,t}(i)}{P_{T,t}}\right)^{-\gamma_T}\left(\frac{P_{T,t}}{P_{H,t}}\right)^{-\phi}\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}(n\nu_t) \tag{2.27}$$

$$\nu_{T,t}^C(i) = \left(\frac{\alpha_y\alpha_C}{n^C}\right)\left(\frac{P_{T,t}^C(i)}{P_{T,t}^C}\right)^{-\gamma_T}\left(\frac{\tau_t^C e_t^C P_{T,t}^C}{P_{H,t}}\right)^{-\phi}\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}(n\nu_t) \tag{2.28}$$

$$\nu_{T,t}^R(i) = \left(\frac{\alpha_y\alpha_R}{1-n-n^C}\right)\left(\frac{P_{T,t}^R(i)}{P_{T,t}^R}\right)^{-\gamma_T}\left(\frac{\tau_t^R e_t^R P_{T,t}^R}{P_{H,t}}\right)^{-\phi}\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}(n\nu_t) \tag{2.29}$$

[8] As usual, the iceberg trade costs are considered symmetric: the iceberg cost to export from EUR to CEE is the same as the cost to export from CEE to EUR

2.3.3 Production

Tradable-good production

There is a continuum of monopolistic firms producing different varieties i of the tradable good. As in Mandelman and Zlate (2021), the tradable good is produced combining abstract tasks, routine tasks and ICT capital according to the following production function:

$$Y_{T,t}(i) = \left\{ \alpha_r^{\frac{1}{\theta}} R_t(i)^{\frac{\theta-1}{\theta}} + (1-\alpha_r)^{\frac{1}{\theta}} \left[\alpha_k^{\frac{1}{\sigma}} K_t(i)^{\frac{\sigma-1}{\sigma}} + (1-\alpha_k)^{\frac{1}{\sigma}} A_t(i)^{\frac{\sigma-1}{\sigma}} \right]^{(\frac{\sigma}{\sigma-1})(\frac{\theta-1}{\theta})} \right\}^{\frac{\theta}{\theta-1}} \tag{2.30}$$

with $\theta > \sigma > 0$. $A_t(i)$ is the amount of abstract input supplied by high-skill workers and $R_t(i)$ is the routine input provided by domestic middle-skill workers or by foreign middle-skill workers through offshoring in firm i. The elasticity of substitution between capital and routine labor θ is assumed to be larger than the elasticity of substitution between capital and abstract labor σ. Hence, ICT capital is a relative complement to abstract labor and a relative substitute to routine labor. Each period, firms maximize the profits they rebate to the large family:

$$Div_{T,t}(i) = \frac{P_{T,t}(i)}{P_{T,t}} Y_{T,t}(i) - r_{k,t}(i) K_t(i) - mc_{a,t}(i) A_t(i) - mc_{r,t}(i) R_t(i) \tag{2.31}$$

where $Div_{T,t}(i)$ is the profit of firm i producing the tradable good, $mc_{a,t}(i)$ and $mc_{r,t}(i)$ are the real marginal costs of abstract and routine tasks for firm i to be defined below and $r_{k,t}(i) = R_{k,t}(i)/P_{T,t}$ is the real rate of return of capital for firm i.

Optimization gives the following factor demands:

$$R_t(i) = \alpha_r \left(\frac{mc_{r,t}(i)}{mc_{T,t}(i)}\right)^{-\theta} Y_{T,t}(i) \tag{2.32}$$

$$A_t(i) = (1-\alpha_r)(1-\alpha_k)\left(\frac{mc_{a,t}(i)}{mc_{ka,t}(i)}\right)^{-\sigma}\left(\frac{mc_{ka,t}(i)}{mc_{T,t}(i)}\right)^{-\theta} Y_{T,t}(i) \tag{2.33}$$

$$K_t(i) = (1-\alpha_r)\alpha_k\left(\frac{r_{k,t}(i)}{mc_{ka,t}(i)}\right)^{-\sigma}\left(\frac{mc_{ka,t}(i)}{mc_{T,t}(i)}\right)^{-\theta} Y_{T,t}(i) \tag{2.34}$$

where $mc_{ka,t}(i) = \left[\alpha_k (r_{K,t}(i))^{1-\sigma} + (1-\alpha_k)(mc_{a,t}(i))^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ and $mc_{T,t}(i)$ is the real marginal cost of the tradable good in firm i. As firms have the same optimizing behavior, aggregation is easily done and they choose the same price: $P_{T,t}(i) = P_{T,t}$. For simplicity and without loss of generality, I choose $P_{T,t} = 1$. As such, optimization gives us $mc_{T,t}(i) = mc_{T,t} = \frac{\gamma_T - 1}{\gamma_T}$, a usual condition.

Abstract tasks

High-skill workers are perfect substitutes between each others and provide abstract tasks used in the production of the tradable good with the same productivity. Abstract labor is the only input required for the production of abstract tasks, defined as:

$$A_t(i) = N_{a,t}(i)\Lambda x_{a,t} \tag{2.35}$$

where $N_{a,t}(i)$ is the number of high-skill workers in firm i and the expression $\Lambda x_{a,t}$ indicates the productivity of workers. Parameter Λ expresses the productivity differential between the different regions that results from technological differences. It is normalized to one for the EUR region and is less than one for the other regions (more details are provided in the Section dedicated to the parametrization). The variable $x_{a,t} > 1$ tracks the relative productivity of abstract workers. The converse variable for manual labor x_m is normalized to one. Therefore, it can be seen as the productivity differential between abstract and manual labor. Abstract workers are paid a real wage $w_{a,t} = W_{a,t}/P_{T,t}$. High-skill workers are perfect substitutes, meaning that aggregation is straightforward. Therefore, the marginal cost of the abstract production is equal to the abstract wage divided by the productivity differential parameters for all firms: $mc_{a,t}(i) = mc_{a,t} = \frac{w_{a,t}}{\Lambda x_{a,t}}$. Finally, the premium π_t is the difference between the income earned by abstract workers and their income if they had instead supplied manual tasks:

$$\frac{\pi_t}{P_{T,t}} = w_{a,t} - w_{m,t} \tag{2.36}$$

Routine tasks

General presentation. Routine input is composed of non-substitutable routine tasks indexed by j.[9] Those tasks follow a uniform distribution on the interval $[0, j_{max}]$ with c.d.f. $G(\cdot)$. Each routine task j can be supplied by any middle-skill worker with the same productivity, domestically (D), or through offshoring to the CEE region (C) or the ROW region (R). As such, index j has no influence for domestic workers, but it is crucial for the offshoring process as it indicates the complexity to offshore a specific task. As the three types of workers are perfectly substitutable for any routine task, firms choose the factor of production with the lowest marginal cost.

A domestic worker supplies an effort $l_t = r_t \Lambda x_{r,t}$ where $x_{r,t}$ tracks the difference of productivity between routine and manual labor and r_t, normalized to 1, is the effort needed to produce any individual task. Therefore, the effort required to produce a task is different from the effort supplied by a worker. Input requirements are considered identical for each firm, meaning that the index i is not necessary to express task effort. I consider that when offshoring firms open a subsidiary in the foreign region and give foreign workers access to the same technology as domestic workers. This means that foreign workers supplying routine labor for EUR firms have the same productivity as domestic EUR routine workers. As

[9] For this part of the model, I mostly use the modeling strategy developed in Ottaviano, Peri, and Wright (2013). I make some changes to their model as replacing migrant workers by a second level of offshoring.

such, when working for a EUR firm, each CEE or ROW worker supplies the same effort l_t. Thus, the routine input in firm i is produced according to the following production function:

$$R_t(i) = N_{f,t}(i) x_{r,t} \Lambda r_t \tag{2.37}$$

with $N_{f,t}(i)$ the number of routine workers in firm i. As explained before, the index j has no influence on the productivity of workers and therefore does not appear in the production function. However, the index is necessary for the expression of the companion price index as the cost of a task depends on the location of the worker:

$$mc_{r,t}(i) = \int_0^{j_{max}} c_{r,t}(i,j) dj \tag{2.38}$$

with $c_{r,t}(i,j)$ the cost of task j in firm i. Each firm pays domestic workers the identical real wage $w_{r,t} = W_{r,t}/P_{T,t}$ that takes into account the premium due to training. We can simply obtain the premium income earned by each domestic routine worker expressed in real terms as the difference of income between what they earn and what they would have earned if employed to supply manual tasks:

$$\frac{\eta_t}{P_{T,t}} = w_{r,t} - w_{m,t} \tag{2.39}$$

Offshoring options. Mandelman and Zlate (2021) consider that for firms from the United States offshoring mostly happens with firms of countries that have the same level of development and is due to countries' specializations. However, it is not the best way to represent offshoring in the present case. As explained in Eurofound (2016), firms in Western European countries also conduct offshoring towards countries with a similar level of development. But, it almost only occurs between countries of the region (for instance, from France to Italy or Spain). This type of offshoring should have little or no effect for the aggregate distribution of employment in the EUR region. Therefore, offshoring due to specialization is not a main concern here and is not taken into account. In this model, I look at offshoring that EUR firms implement for cost reasons, towards countries with a lower level of development.[10] This type of offshoring should indeed have an effect on employment distribution in Western European countries.

When offshoring, firms pay workers the amount they would have earned if employed by their national firms to supply routine tasks. Indeed, all routine workers of a same region are identical and the difference in productivity is simply due to the difference in firms' technology. Therefore, EUR firms pay CEE workers $w^C_{r,t}T^C_t$, with $w^C_{r,t}T^C_t$ the routine CEE wage expressed in the currency of the EUR region. The variable $T^C_t = e^C_t P^C_{T,t}/P_{T,t}$ is the terms of trade between the EUR region and the CEE region. Similarly, a ROW worker is paid a wage $= w^R_{r,t}T^R_t$ when employed by EUR firms, with $T^R_t = e^R_t P^R_{T,t}/P_{T,t}$ the terms of trade between EUR and ROW. Those wages are also identical whatever the offshoring firm.

Firms have to pay a supplementary cost $F^O_t(j) = \zeta^O(j)\tau^O_t$ for $O = \{C, R\}$ and with τ^O_t the trade cost defined earlier for each task produced abroad. The variable $\zeta^O(j) = z^O(1+j)$ is a task-specific cost that increases with the index j: the higher j, the more complex it is to offshore the task, and thus the higher the offshoring cost. A high j indicates for example the importance of knowing the firm home language or its culture to perform the task. It may also illustrate that the skills required to perform the task are absent in the region and workers must be trained to perform it.

Location decisions. Given the above assumptions, the costs to produce a specific task domestically $c_{D,t}(j) = c_{D,t}$, to offshore it to the CEE region $c_{OC,t}(j)$ or to the ROW region

[10] In the model, the impossibility for CEE firms to offshore to the EUR region or for ROW firms to offshore to any region is simply due to the fact that $w_{r,t}/T^R_t > w^C_{r,t}T^C_t/T^R_t > w^R_{r,t}$ as explained below. Therefore, it is always cheaper for ROW firms to produce domestically than to offshore. Similarly, there is no task that is cheaper to offshore to the EUR region than to produce domestically for CEE firms. Offshoring by CEE firms to the ROW region could be added to the model. However, it has very little impact on the dynamics in the EUR region. As such, this type of offshoring is not included to simplify the model. Nevertheless, the model and results with offshoring CEE firms are presented in Appendix 2.7.6.

$c_{OR,t}(j)$ are expressed as follows:

$$c_{D,t} = \frac{w_{r,t}}{x_{r,t}\Lambda} \tag{2.40}$$

$$c_{OC,t}(j) = F_t^C(j)\frac{w_{r,t}^C T_t^C}{x_{r,t}\Lambda} \tag{2.41}$$

$$c_{OR,t}(j) = F_t^R(j)\frac{w_{r,t}^R T_t^R}{x_{r,t}\Lambda} \tag{2.42}$$

The assumption of perfect substitution means that a task is offshored to the CEE region rather than produced domestically whenever:

$$c_{D,t} \geq c_{OC,t}(j) \tag{2.43}$$

To insure that some offshoring to the CEE region takes place, we need to assume that $c_{D,t} > c_{OC,t}(0)$. Similarly, a task is offshored to the ROW region rather than produced domestically whenever:

$$c_{D,t} \geq c_{OR,t}(j) \tag{2.44}$$

and I assume that $c_{D,t} > c_{OR,t}(0)$. Finally, a task is offshored to region ROW rather than to region CEE whenever:

$$c_{OC,t}(j) \geq c_{OR,t}(j) \tag{2.45}$$

To allocate tasks between both types of offshoring, I need two other assumptions. First, I consider that $c_{OC,t}(0) \geq c_{OR,t}(0)$.[11] Second, I assume that $(\zeta_t^C(j))' < (\zeta_t^R(j))'$ so that the difficulty to offshore to region ROW increases faster in j than the difficulty to offshore to region CEE.[12] With those assumptions, offshoring occurs in each region. The previous

[11] This assumption is easily justified by the fact that wages are lower in countries of Southern Asia than in Central and Eastern Europe.

[12] This can easily be justified by the stronger difference in culture and language between Western Europe and Asia than between both regions of Europe.

assumptions imply that there is only one time-dependent "marginal ROW offshored task" $j = J_{CR,t}$ such that

$$c_{OC,t}(J_{CR,t}) = c_{OR,t}(J_{CR,t}) \tag{2.46}$$

This means that for all tasks $j \leq J_{CR,t}$, it is cheaper to offshore tasks to the ROW region than to the CEE region. On the contrary, it is cheaper to offshore tasks to the CEE region than to the ROW region when $j \geq J_{CR,t}$. Moreover, for all three types of workers to supply labor, we need $c_{OC,t}(J_{CR,t}) < c_{D,t} < c_{OC,t}(j_{max})$. This gives us a "marginal CEE offshored task" $j = J_{DC,t}$ such that:

$$c_{D,t} = c_{OC,t}(J_{DC,t}) \tag{2.47}$$

The resulting task allocation is presented in Figure 2.2 and the cost of each task is defined as follows whatever the EUR firm:

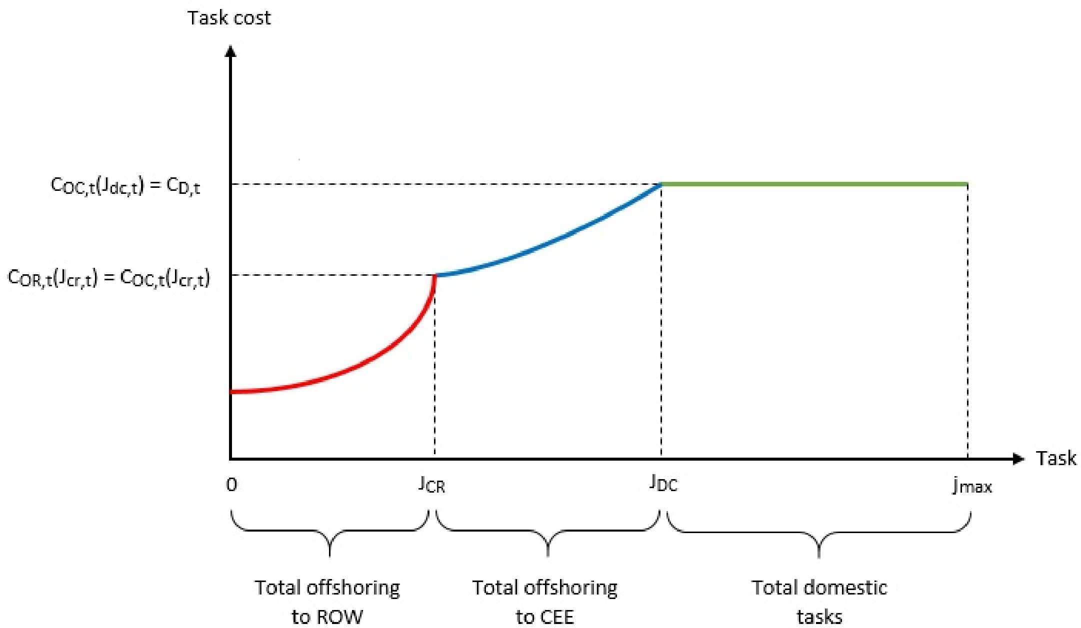
$$c_t(j) = c_t(i,j) = \begin{cases} c_{OR,t}(j) & = F_t^R(j)\frac{w_{r,t}^R T_t^R}{x_{r,t}\Lambda} & 0 \leq j < J_{CR,t} \\ c_{OC,t}(j) & = F_t^C(j)\frac{w_{r,t}^C T_t^C}{x_{r,t}\Lambda} & J_{CR,t} \leq j < J_{DC,t} \\ c_{D,t} & = \frac{w_{r,t}}{x_{r,t}\Lambda} & J_{DC,t} \leq j < j_{max} \end{cases}$$

The routine average marginal cost $mc_{r,t}(i) = mc_{r,t}$ can be expressed as the weighted average of the average cost of each type of workers:

$$mc_{r,t} = G(J_{CR,t})mc_{OR,t} + \big[G(J_{DC,t}) - G(J_{CR,t})\big]mc_{OC,t} + \big[1 - G(J_{DC,t})\big]mc_{D,t} \tag{2.48}$$

with the average (marginal) cost of a domestic worker, a worker of the CEE region, and of

Figure 2.2: Routine worker decision



the ROW region expressed respectively as:

$$mc_{D,t} = \frac{w_{r,t}}{x_{r,t}\Lambda} \tag{2.49}$$

$$mc_{OC,t} = \frac{1}{J_{DC,t} - J_{CR,t}} \int_{J_{CR,t}}^{J_{CD,t}} F_t^C(j) \frac{w_{r,t}^C T_t^C}{x_{r,t}\Lambda} \, dj \tag{2.50}$$

$$mc_{OR,t} = \frac{1}{J_{CR,t}} \int_{0}^{J_{CR,t}} F_t^R(j) \frac{w_{r,t}^R T_t^R}{x_{r,t}\Lambda} \, dj \tag{2.51}$$

As firms have the same optimizing behavior, aggregation is easy. The total of workers supplying routine tasks for the EUR firms is $N_{f,t} = N_{D,t} + N_{OC,t} + N_{OR,t}$ where $N_{OR,t}$, $N_{OC,t}$ and $N_{D,t}$ are respectively the amount of ROW workers, CEE workers and domestic workers supplying routine labor for EUR firms. As EUR routine workers can only work for domestic firms, $N_{D,t} = N_{r,t}$. We can express the shares of each type of workers over the number of workers producing routine tasks for EUR firms as:

$$\frac{N_{OR,t}}{N_{f,t}} = G(J_{CR,t}), \qquad \frac{N_{OC,t}}{N_{f,t}} = G(J_{DC,t}) - G(J_{CR,t}), \qquad \frac{N_{D,t}}{N_{f,t}} = 1 - G(J_{DC,t}) \tag{2.52}$$

Finally, given the assumption of uniform distribution, we can easily define the location decision cutoffs as:

$$J_{CR,t} = j_{max}\frac{N_{OR,t}}{N_{f,t}}, \qquad J_{DC,t} = j_{max}\frac{N_{OC,t} + N_{OR,t}}{N_{f,t}} \tag{2.53}$$

Figure 2.3 indicates the direct effect of a decrease in the trade cost between the EUR and CEE regions τ_t^C on the shares of each type of workers. For any task, the cost of offshoring to the CEE region becomes lower. As such, it has the direct effect of increasing the share of the tasks offshored to the CEE region at the expense of both domestic workers and ROW offshoring. Besides, the cost at which offshoring to the ROW region and the CEE region is equal decreases. Then, Figure 2.4 shows the direct effect of a decrease in the trade cost between the EUR and ROW regions τ^R on the offshoring decision. This time, the cost of offshoring any task to the ROW region becomes lower. As a consequence, the share of routine tasks offshored to the ROW region logically increases. But, the direct impact only diminishes the share of tasks offshored to the CEE region. It has no effect on domestic workers (except if the trade cost decreases so much that there is no offshoring to the CEE region anymore). This time, the cost at which offshoring to the CEE or ROW regions is identical increases. If both trade costs decrease at the same time, it has for direct consequence a decrease in the amount of tasks produced domestically as more work is offshored. However, the direct effect on each type of offshoring is unknown and depends on the relative size of the decrease in each trade cost.

Routine tasks in the other regions. In the CEE region, firms only hire domestic workers

Figure 2.3: Direct effect of a decrease in the trade cost between the EUR and CEE regions

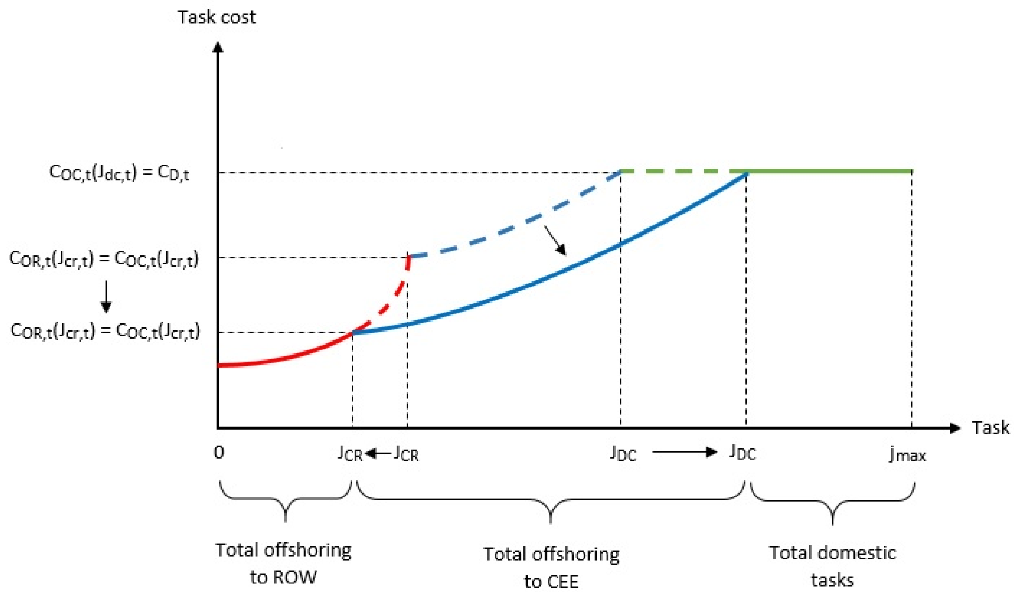
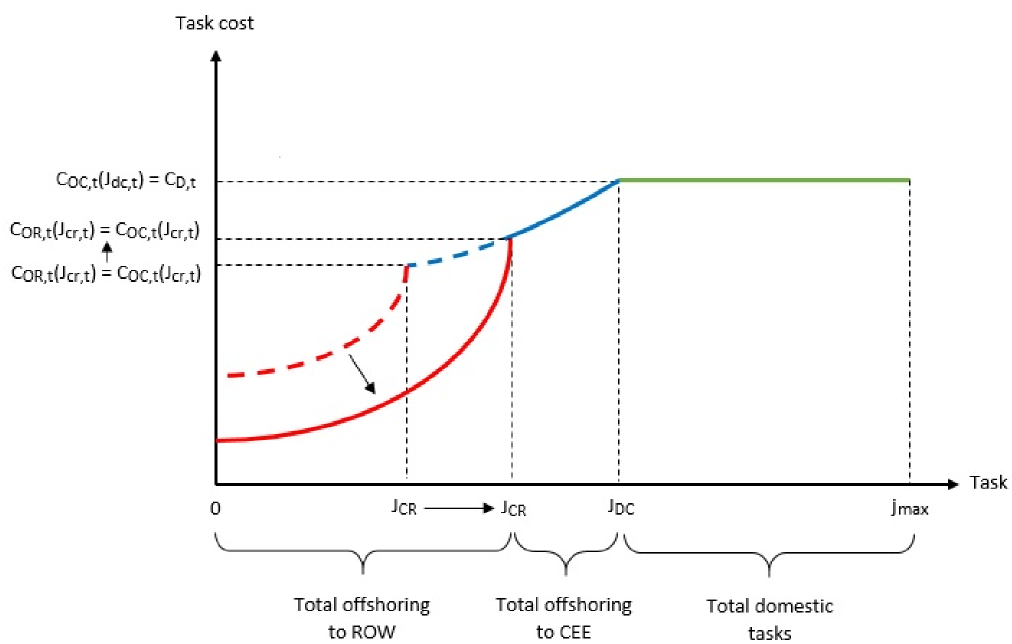


Figure 2.4: Direct effect of a decrease in the trade cost between the EUR and ROW regions



to supply routine tasks.[13] Each worker supplies

$$l_t^C = r_t^C \Lambda^C x_r \tag{2.54}$$

They are paid the same real wage $w_{r,t}^C = W_{r,t}^C / P_{T,t}^C$. The marginal cost is equal to the wage divided by the productivity differential parameters: $mc_{r,t}^C(i) = mc_{r,t}^C = \frac{w_{r,t}^C}{\Lambda_t^C x_r}$ for any task. The total number of workers providing routine labor for CEE firms is $N_{f,t}^C = N_{D,t}^C$. We can also express the number of workers supplying routine tasks as the sum of routine workers working domestically and those working for EUR firms:

$$N_{r,t}^C = \left(N_{D,t}^C + \frac{n}{n^C} N_{OC,t} \right) \tag{2.55}$$

2.3.4 Non-tradable sector

Production in the non-tradable sector is operated by monopolistic firms that only use manual labor as input. Low-skill workers supply manual tasks with the same productivity. As such, the non-tradable production function $Y_{N,t}(i)$ for firm i is defined as

$$Y_{N,t}(i) = N_{m,t}(i) \Lambda x_{m,t} \tag{2.56}$$

with $x_{m,t}$ normalized to 1 as explained before. Those firms want to maximize the profits they rebate to the domestic family:

$$Div_{N,t}(i) = \frac{P_{N,t}(i)}{P_{N,t}} Y_{N,t}(i) - mc_{m,t}(i) Y_{N,t}(i) \tag{2.57}$$

with $Div_{N,t}(i)$ the profits of a firm i that produces the non-tradable good and $mc_{m,t}(i)$ the real marginal cost to produce the non-tradable good in firm i. In each firm, workers earn the basic real wage $w_{m,t} = W_{m,t}/P_{T,t}$. As such, the marginal cost equals the wage

[13] The same equations stand for the ROW region.

divided by the productivity differential: $mc_{m,t}(i) = \frac{w_{m,t}}{\Lambda x_{m,t}}$. Furthermore, due to their maximizing behaviors, firms choose the same price. This means that $P_{N,t} = P_{N,t}(i)$ and that $mc_{m,t} = mc_{m,t}(i) = \frac{\gamma_N - 1}{\gamma_N} P_{N_t}$.

2.3.5 Equilibrium

Aggregate production is simply the sum of productions of tradable and non-tradable goods:

$$Y_t = Y_{T,t} + Y_{N,t} \tag{2.58}$$

where the aggregate productions of the tradable good $Y_{T,t}$ and of the non-tradable good $Y_{N,t}$ are respectively:

$$Y_{T,t} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\gamma_T}} \int_0^n Y_{T,t}(i)^{\frac{\gamma_T - 1}{\gamma_T}} di \right]^{\frac{\gamma_T}{\gamma_T - 1}} \tag{2.59}$$

$$Y_{N,t} = \left[\left(\frac{1}{n} \right)^{\frac{1}{\gamma_N}} \int_0^n Y_{N,t}(i)^{\frac{\gamma_N - 1}{\gamma_N}} di \right]^{\frac{\gamma_N}{\gamma_N - 1}} \tag{2.60}$$

The demand for non-tradable goods is divided between consumption and investment. As such, we obtain respectively for EUR, CEE and ROW regions the following equations for the demand of non-tradable goods:

$$Y_{N,t} = \left(\frac{P_{N,t}}{P_t} \right)^{-\rho} (1 - \alpha_y)(C_t + I_t) \tag{2.61}$$

$$Y_{N,t}^C = \left(\frac{P_{N,t}^C}{P_t^C} \right)^{-\rho} (1 - \alpha_y^C)(C_t^C + I_t^C) \tag{2.62}$$

$$Y_{N,t}^R = \left(\frac{P_{N,t}^R}{P_t^R} \right)^{-\rho} (1 - \alpha_y^R)(C_t^R + I_t^R) \tag{2.63}$$

Tradable goods can be used for consumption and investment but also for the training costs.

Therefore, demands for EUR, CEE and ROW tradable goods are expressed respectively as:

$$Y_{T,t} = \frac{f_{Na,t}}{P_t} N_{Na,t} + \frac{f_{Nr,t}}{P_t} N_{Nr,t} + y^E_{E,t} + y^C_{E,t} + y^R_{E,t} \tag{2.64}$$

$$Y^C_{T,t} = \frac{f^C_{Na,t}}{P^C_t} N^C_{Na,t} + \frac{f^C_{Nr,t}}{P^C_t} N^C_{Nr,t} + y^C_{C,t} + y^E_{C,t} + y^R_{C,t} \tag{2.65}$$

$$Y^R_{T,t} = \frac{f^R_{Na,t}}{P^R_t} N^R_{Na,t} + \frac{f^R_{Nr,t}}{P^R_t} N^R_{Nr,t} + y^R_{R,t} + y^E_{R,t} + y^C_{R,t} \tag{2.66}$$

with $y^J_{I,t}$ total consumption and investment demand in region J for the tradable good from region I.[14] As there is no financial markets, the value of the tasks offshored abroad plus the imports of tradable goods must equal the value of the received offshored tasks plus the exports of tradable goods. Hence, we obtain the following equations of international trade for respectively the EUR, CEE and ROW regions:[15]

$$\begin{aligned} &nN_{f,t}\Big[G(J_{CR})w^R_{r,t}T^R_t + (G(J_{DC}) - G(J_{CR}))w^C_{r,t}T^C_t\Big]\frac{P_{T,t}}{P_t} \\ &\qquad + n^C y^E_{C,t} S^C_t + n^R y^E_{R,t} S^R_t = n\big(y^C_{E,t} + y^R_{E,t}\big) + \Gamma \end{aligned} \tag{2.67}$$

$$n^R y^C_{R,t} S^{CR}_t + n\frac{y^C_{E,t}}{S^C_t} = (G(J_{DC}) - G(J_{CR}))w^C_{r,t} n N_{f,t} \frac{P^C_{T,t}}{P^C_t} + n^C\big(y^E_{C,t} + y^R_{C,t}\big) + \Gamma^C \tag{2.68}$$

$$n\frac{y^R_{E,t}}{S^R_t} + n^C\frac{y^R_{C,t}}{S^{CR}_t} = G(J_{CR})w^R_{r,t} n N_{f,t}\frac{P^R_{T,t}}{P^R_t} + n^R\big(y^E_{R,t} + y^C_{R,t}\big) + \Gamma^R \tag{2.69}$$

where S_t is the real exchange rate in terms of the aggregate price index P_t: $S^C_t = P^C_t / P_t$. Besides, Γ, Γ^C and Γ^R are respectively the steady-state trade deficits of the EUR, CEE and ROW regions with $\Gamma^R = -\frac{\Gamma}{S^R} - \frac{\Gamma^C}{S^{CR}}$.

[14] Their precise expressions are given in Appendix 2.7.2.

[15] As tariffs are only a small share of the trade costs, I consider that all supplementary trade and offshoring costs are purely wasteful frictions, they are not rebated to the households.

2.4 Parameter values and driving forces

2.4.1 Parameter values

Size and preferences. Most parameters are calibrated to match targets for the year 2000, the starting point of the analysis. The three regions of the model represent the different areas of interest of the chapter. The EUR region is composed of the fifteen countries that joined the European Union before 2004.[16] The CEE region is constituted of the countries of Central and Eastern Europe that joined the European Union since 2004.[17] Finally, the ROW region includes the developing countries of Asia that are the main partners of the European Union: China, India and Indonesia. Therefore, the size of each region represents its non-agricultural labor force: The EUR, CEE and ROW countries have a respective size of $n = 0.23$, $n^C = 0.05$, $n^R = 0.72$. Besides, as I am focusing on structural changes and not business cycle issues, a period corresponds to a year. Hence, β is calibrated to 0.96.

Employment and labor productivity. The relative amount of each type of labor is set to match labor-force weighted average for each region using the data from the International Labour Organization database (ILOSTAT) and from the European Center for the Development of Vocational Training (CEDEFOP) for 2000.[18] This gives the following shares for the EUR region: $\bar{N}_a = 38.5\%$, $\bar{N}_r = 34.4\%$ and $\bar{N}_m = 27.1\%$. For the CEE region, we have $\bar{N}_a^C = 36.1\%$, $\bar{N}_r^C = 38.0\%$ and $\bar{N}_m^C = 25.9\%$; and for the ROW region, I obtain $\bar{N}_a^R = 23.5\%$, $\bar{N}_r^R = 44.6\%$ and $\bar{N}_m^R = 31.9\%$. Concerning the earnings, data is not available for all countries. Nevertheless, we can obtain some regional estimates by using data from the ILOSTAT. Earnings of routine workers are around 2.4 times higher in the EUR region than the CEE region and 8 times higher in the EUR region than in the ROW region. I use those data to set the productivity differential between countries: $\Lambda = 1$, $\Lambda^C = 1/2.4$

[16]Those countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

[17]Those countries are Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia.

[18]The precise division between the three categories is presented in Appendix 2.7.1.

and $\Lambda^R = 1/8$. I use the same data to set the productivity differentials between sectors: $x_r = 1.3$ and $x_a = 2.2$. Furthermore, the annual job separation rate is $\delta_a = \delta_r = 0.115$, which corresponds to a 3% quarterly separation rate as found for European countries in Maillard (2020) based on the country estimates in Hobijn and Şahin (2009). These numbers imply an abstract training cost of $f_{Na} = 7.54$ and a routine training cost of $f_{Nr} = 1.89$.

Production. The depreciation rate of capital is $\delta_k = 0.20$ as estimated by Eden and Gaggl (2018). Besides, α_k is calibrated to match the following shares of ICT-capital income in total income: 6.5% for EUR, 5% for CEE and 1% for ROW.[19] As such, $\alpha_k = 0.195$, $\alpha_k^C = 0.149$ and $\alpha_k^R = 0.048$. Moreover, as a consequence of matching the shares of routine labor, abstract labor and ICT capital with the data, I must impose $\alpha_r = 0.528$, $\alpha_r^C = 0.485$ and $\alpha_r^R = 0.568$. The elasticity of substitution between tradable varieties γ_T and between non-tradable varieties γ_N are both set to 6 as in Brückner and Pappa (2012), which produces a gross steady-state markup of 20%. I follow Mandelman and Zlate (2021) for the elasticity of substitution between tradable and non-tradable goods ($\rho = 0.44$) and for the elasticity of substitution between ICT capital and abstract labor ($\sigma = 0.67$). Finally, I impose $\theta = 5$ for the elasticity between abstract and routine labor, a value that provides the best fit of the model with the data in terms of offshoring and polarization.[20]

Offshoring, trade and openness. The share of routine labor that is offshored is pinned down using the World Input-Output Tables (WIOT). Those tables report imports and demand of domestic goods by firms and final consumers by sector and country of origin with a high level of disaggregation (see Timmer et al. (2015) for more details). I consider that offshorable tasks correspond to production made by the manufacturing sector for the manufacturing sector. By summing this type of imports from each country in each region, I obtain the share of those goods received by the EUR region from CEE and ROW regions.

[19]The calibration for the EUR region follows the estimation of Eden and Gaggl (2018) for the United States when removing non-ICT capital.

[20]Results for a lower θ are presented in Appendix 2.7.5 and commented in details at the end of Section 2.5.2.

I consider that this share corresponds to the share of routine labor offshored by firms of the EUR region. As such, I find that the share of routine labor offshored to ROW is $G(J_{OR}) = 0.9\%$ and that the share routine labor offshored to CEE is $G(J_{DC}) - G(J_{OR}) = 1.9\%$. I choose $j_{max} = 1.5$ to match as closely as possible offshoring data over the period 2000-2016. Given the target quantity of offshoring, the level of trade costs and the wage differentials between countries, the cost parameters for offshoring to the CEE and ROW regions are respectively $z^C = 1.492$ and $z^R = 4.218$. As usual in the international macroeconomic literature, I choose a value of $\phi = 1.5$ for the trade elasticity. I also normalize the terms of trade $\bar{T}^C = \bar{T}^R = \bar{T}^{CR} = 1$ in the steady-state.[21] The size of the openness towards each region are set to match the ratio of import to final-good demand in each region, using the WIOT.[22] I obtain $\alpha_C = 0.0121$, $\alpha_R = 0.0168$, $\alpha_E^C = 0.2314$, $\alpha_R^C = 0.0161$, $\alpha_E^R = 0.0511$, $\alpha_C^R = 0.0023$. Those numbers imply the following small trade surplus for the EUR and ROW regions: $\Gamma = -0.0004$ and $\Gamma^R = -0.0003$ and a trade deficit of $\Gamma^C = 0.0007$ for the CEE region. Finally, consistency between the chosen parameter values and the structural equations of the model constrains the size of the tradable-good sector and requires $\alpha_y = 0.834$, $\alpha_y^C = 0.956$ and $\alpha_y^R = 0.747$. Parameter values are summarized in Table 2.1.

2.4.2 Driving forces

Trade costs. I feed the model with a time-varying and exogenous measure of trade costs each period. This way, I can simulate a decrease in the costs of offshoring and in the trade of final goods. To obtain those costs, I use the ESCAP-World Bank (2021) bilateral-iceberg trade cost database based on Novy (2013). It gives the weighted average tariffs and non-tariffs costs – reported as $(\tau_t - 1) \times 100$ – between two countries annually for

[21] As an alternative, I could set terms of trade at the value that yields a zero steady-state trade deficit. The results are basically insensitive.

[22] I remove the goods that are produced by and sold to the manufacturing sector from the calculation, as I considered them as offshoring and not final goods. Precise final good import shares over total demand are indicated in Appendix 2.7.3.

Table 2.1: Parameter values for the baseline model

Common parameters	**Symbol**	**Value**		
Discount factor	β	0.96		
Depreciation rate of ICT capital	δ_K	0.20		
Job separation rates	$\delta_a = \delta_r$	0.115		
Cost of abstract training	f_{Na}	7.54		
Cost of routine training	f_{Nr}	1.89		
Elasticity of substitution tradable varieties	γ_T	6		
Elasticity of substitution non-tradable varieties	γ_N	6		
Trade elasticity	ϕ	1.5		
Elasticity of substitution tradable and non-tradable goods	ρ	0.44		
Elasticity of substitution ICT capital and abstract labor	σ	0.67		
Elasticity of substitution routine and abstract labor	θ	5		
Steady-state routine productivity	$\bar{x}_r$	1.3		
Steady-state abstract productivity	$\bar{x}_a$	2.2		
Trade and offshoring parameters	**Symbol**	**Value**		
Share of routine production offshored to CEE	$\bar{G}(J_{DC}) - \bar{G}(J_{CR})$	0.019		
Share of routine production offshored to ROW	$\bar{G}(J_{CR})$	0.009		
Trade cost between EUR and CEE	τ^C	1.6		
Trade cost between EUR and ROW	τ^R	2.02		
Trade cost between CEE and ROW	τ^{CR}	2.81		
Cost parameter for CEE offshoring	z^C	1.492		
Cost parameter for ROW offshoring	z^R	4.218		
Offshoring cost upper bound	j_{max}	1.5		
Region-dependent parameters	**Symbol**	**EUR**	**CEE**	**ROW**
Region size	n	0.23	0.05	0.72
Steady-state share of abstract labor	$\bar{N}_a$	0.385	0.361	0.235
Steady-state share of routine labor	$\bar{N}_r$	0.344	0.380	0.446
Steady-state share of manual labor	$\bar{N}_m$	0.271	0.259	0.319
Productivity level	Λ	1	1/2.4	1/8
Share of ICT capital	α_k	0.195	0.149	0.048
Share of routine labor	α_r	0.528	0.485	0.568
Share of the tradable sector	α_y	0.834	0.956	0.747
Trade deficit	Γ	-0.0004	0.0007	-0.0003
Openness to EUR goods	α_E		0.2314	0.0511
Openness to CEE goods	α_C	0.0121		0.0023
Openness to ROW goods	α_R	0.0168	0.0161	

the manufacturing and agricultural sectors for most of the countries we are interested in.[23] Although tariffs were already quite low in 2000 between most countries, this database also takes into account all the costs associated with trade: administrative, transportation or communication costs for instance. I use the total trade cost only for the manufacturing sector to build these driving forces.

I adopt the following method to compute the average trade cost between two regions. First, I calculate a preliminary cost of import by region I from region J by averaging the import cost between each pair of countries i and j where i belongs to region I and j to region J. This average is weighted by the size of manufacturing imports by country i from country j, that I obtain from the WIOT.[24] Second, although the trade cost τ equals one inside a country, the regions of the model include several countries. Therefore, I need to divide the cost of imports of region I from region J by the trade cost internal to region I. This internal trade cost is computed using the same method, except that it is the weighted-average of the trade cost between each pair of countries i_S and i_R that both belong to I, and that i_S and i_R can be the same. This allows to also take into account the demand of domestic goods for which the trade cost is one. Finally, trade costs are considered symmetric in the literature and in the ESCAP-World Bank database. I follow this practice here. I compute the final trade cost between I and J as an average between the cost of import by I from J and the cost of import by J from I. This average is weighted by the sum of manufacturing imports of each region from the other. To sum up, the trade cost $\tau_t^{IJ} = \tau_t^{JI}$ between two

[23] Data are not available for all years for The Netherlands, Hungary and Estonia, as such those countries are removed from the average calculation.

[24] As data after 2014 are not available in the WIOT, I use the manufacturing data of 2014 for 2015 and 2016.

different regions I and J equals:

$$\begin{aligned}\tau_t^{IJ} = & \frac{\frac{\sum_{i\in I}\sum_{j\in J}\tau_t^{ij}Y_{T,t}^{ij}}{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ij}}}{\frac{\sum_{j_S\in J}\sum_{j_R\in J}\tau_t^{j_Sj_R}Y_{T,t}^{j_Sj_R}}{\sum_{j_S\in J}\sum_{j_R\in J}Y_{T,t}^{j_Sj_R}}} \times \frac{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ij}}{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ij}+Y_{T,t}^{ji}} \\ & + \frac{\frac{\sum_{i\in I}\sum_{j\in J}\tau_t^{ji}Y_{T,t}^{ji}}{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ji}}}{\frac{\sum_{i_S\in I}\sum_{i_R\in I}\tau_t^{i_Si_R}Y_{T,t}^{i_Si_R}}{\sum_{i_S\in I}\sum_{i_R\in I}Y_{T,t}^{i_Si_R}}} \times \frac{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ji}}{\sum_{i\in I}\sum_{j\in J}Y_{T,t}^{ij}+Y_{T,t}^{ji}}\end{aligned} \tag{2.70}$$

with $I, J = \{E, C, R\}$, $I \neq J$ and $Y_{T,t}^{ij}$ the total manufacturing imports by j from i.

For the year 2000, the starting value for the analysis, I obtain the following values of trade costs: $\tau^C = 1.60$ between EUR and CEE, $\tau^R = 2.02$ between EUR and ROW and $\tau^{CR} = 2.81$ between CEE and ROW. The evolution of these trade costs between 2000 and 2016 are shown in Appendix 2.7.3 in Figure 2.9. Trade costs are characterized by a decreasing trend during the period. The cost surplus due to trade is more than divided by two between EUR and CEE. This is notably the consequence of the entry of Central and Eastern European countries in the European Union in 2004 and 2007. Costs also strongly decrease for trade with the ROW region, especially with the entry of China in the World Trade Organization in 2001.

ICT-capital prices. Second, I use the decrease in ICT-capital prices to model the increase in ICT-capital stocks. ICT-capital prices, investment and stock are available in the EU KLEMS database for most European Union countries (see Van Ark and Jäger (2017)).[25] I take from the database the prices of computing equipment, communication equipment, and computer software and databases. First, I compute an average ICT-capital price per country

[25] Data are not available for Belgium, Bulgaria, Hungary, Poland and Romania for all or some years. Those countries are not included in the calculation. As such, some of the main countries of the CEE region are not included. However, the ICT-capital price in the CEE region has little influence on the employment dynamics in the EUR region which is the main focus of this chapter. Therefore, the estimation I obtain for the ICT-capital price in the CEE region is sufficient considering the objective of this chapter.

by weighting the prices of each of the three types of ICT capital by its corresponding stock. Then, to compute the price average for the EUR and the CEE regions, I weight the average price per country by the total ICT-capital stock of the corresponding country. Furthermore, I need to take into account the general inflation on the prices of all goods in each region. To do so, I use a country index of production price with the year 2000 as basis. To compute the regional price index, I weight the price of each country of the region by its gross value added. Finally, I divide the previously computed ICT-capital price by the production price index for each region. To sum up, the relative ICT-capital price index $P^J_{k,t}$ for region J is defined as:

$$P^J_{k,t} = \frac{\frac{\sum_{j\in J}\sum_{l\in L} P^j_{kl,t} K^j_{l,t}}{\sum_{j\in J}\sum_{l\in L} K^j_{l,t}}}{\frac{\sum_{j\in J} P^j_{V,t} V^j_t}{\sum_{j\in J} V^j_t}} \tag{2.71}$$

with V^j_t the gross value added in volume of country j belonging to region J, $P^j_{V,t}$ its associated price equals to 1 in 2000 and $P^j_{kl,t}$ the price of ICT-capital of type $l \in L$ in country j.

Details of the ICT-capital price movements for the EUR and CEE regions between 2000 and 2016 are presented in Figure 2.10 in Appendix 2.7.3. For both regions, those prices fall until 2008, decreasing by around 30%. However, on the second half of the period, the decrease slows down for the EUR region and prices even stagnate for the CEE region. Finally, as no data is available for the ROW region, I consider that there is no change in ICT-capital price in that region in the baseline model.[26]

[26] As a robustness check, I also look at the dynamics of the model if I consider that the price of ICT capital in the ROW region follows the same dynamics as the one in the CEE region. I show in Figure 2.13 in Appendix 2.7.5 that it has no effect on the main variables of interest.

2.5 Historical analysis

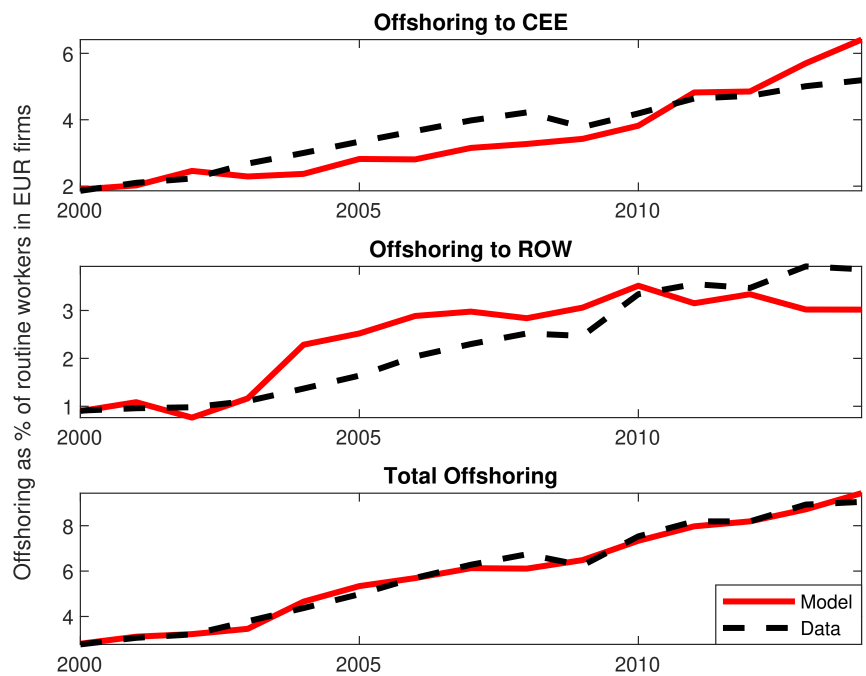
The objective of this section is to study the role of automation and international trade on the structural dynamics of employment distribution in Western Europe between 2000 and 2016. First, I look at the predictions of the baseline model. Then, I run some counterfactual analyses to understand the precise role of each driving force on the changes of employment distribution. Finally, I conduct a welfare exercise to study the consequences of those changes on aggregate well-being.

2.5.1 Predictions of the baseline model

The model is solved using perfect-foresight non-linear simulations in Dynare (see Adjemian et al. (2011)). First, Figure 2.5 compares the offshoring dynamics produced by the model with the data between 2000 and 2014. To obtain the data, I apply the method explained in the previous section, using the WIOT. Unfortunately, data is not available after 2014. As we can observe, the model replicates very precisely the offshoring pattern of Western European firms. The levels of offshoring to CEE and ROW are very close to the data although there are a bit more volatile. In the middle of the period, offshoring to the ROW region is slightly overestimated while offshoring to CEE is a bit underestimated. However, more importantly, total offshoring is almost perfectly estimated for the whole period. This validates my modeling strategy for offshoring decisions and insures that offshoring occurs at an empirically realistic pace in the model, which can matter for the dynamics of the distribution of employment.

My main results are shown in Figure 2.6. It reports the changes in terms of the occupational distribution of employment for Western European countries both in the model and in the data. The model does a very good job at replicating the typical polarization of employment. The fall of the routine labor share is well depicted: it drops from 34.4% to 28.4% of the non-agricultural labor force in the model while it falls from 34.4% to 27.8% in the data.

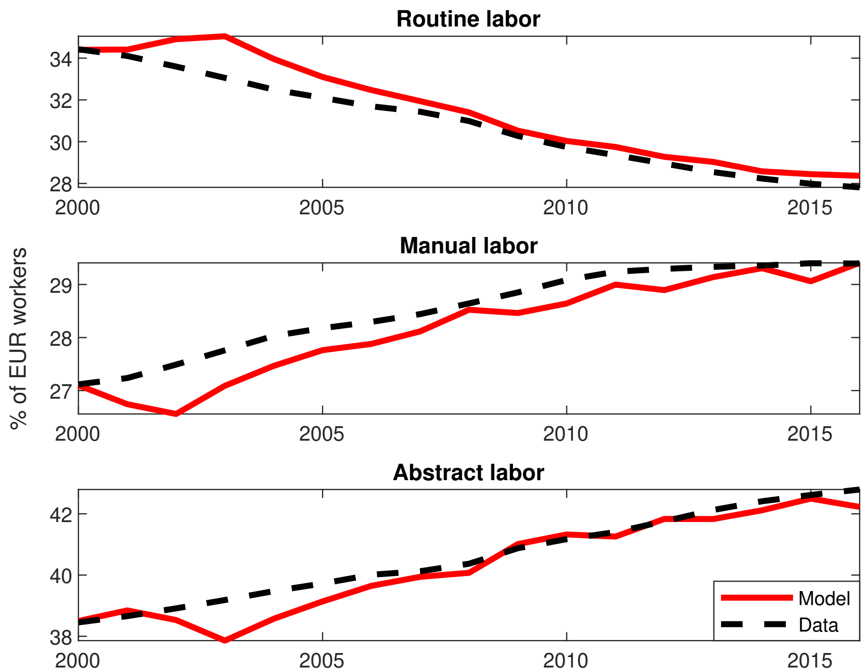
Figure 2.5: Offshoring dynamics



The increase in the abstract labor share is also well reproduced. It goes from 38.5% to 42.2% in the model while it reaches 42.8% in the data. Finally, the rise of the share of manual workers is perfectly replicated: it increases from 27.1% to 29.4% both in the model and the data.

These dynamics can be understood through the lens of the model. Both driving forces imply a fall in the amount of domestic routine workers. First, the decrease in ICT-capital prices leads firms to increase automation by building up the stock of ICT capital and substitute routine workers with machines. Second, the fall of trade costs lowers the cost of offshored labor. Therefore, EUR firms replace domestic routine workers by routine workers of the other regions. As such, less workers train to perform routine tasks in the EUR region and

Figure 2.6: Employment dynamics



more workers have to supply manual tasks. Finally, as ICT capital and abstract workers are relative complements, the increase in the stock of ICT capital raises the share of abstract labor. Now that I have shown that my model is able to replicate the observed polarization of labor markets in Western European countries, I look at the impact of the driving forces separately to precisely understand which is the key factor in explaining the observed changes in the distribution of employment.

2.5.2 Counterfactual analysis

As a counterfactual exercise, I make the model run with only one driving force at a time. Figure 2.7 and Table 2.2 show the distinct roles of automation and international trade on the dynamics of the occupational distribution of employment in Western Europe. As we can see, the decrease in the ICT-capital price is the main factor explaining the polarization of employment in the model. It explains the totality of the rise in high-skill workers supplying abstract tasks. A small effect coming from the increase in final good trade was to be expected. Indeed, the fall of trade costs dampens the price of the tradable good produced by EUR firms. As such, the demand for their good should rise and have a small positive effect on both abstract and routine workers producing this good. But, I show in Appendix 2.7.4 that, due to the relatively low level of final good trade between the three regions, it has almost no impact on the changes of the employment distribution. The exogenous dynamics of trade costs only modify the employment distribution through offshoring decisions, which has no impact on the share of abstract labor. As such, only automation has an up-skilling effect in the model, driving more individuals to train to become high-skill workers. Nevertheless, offshoring has some impact on the changes in the shares of manual and routine workers, as expected. But, this impact is quantitatively much lower than the effect coming from automation. Indeed, the decrease in the routine labor share due to the fall of ICT-capital price is 4.4 times higher than the decrease caused by the fall of trade costs (-4.99 percentage points versus -1.13pp). Finally, automation has an impact on the rise of the share of manual labor that is 25% higher than the effect of international trade.

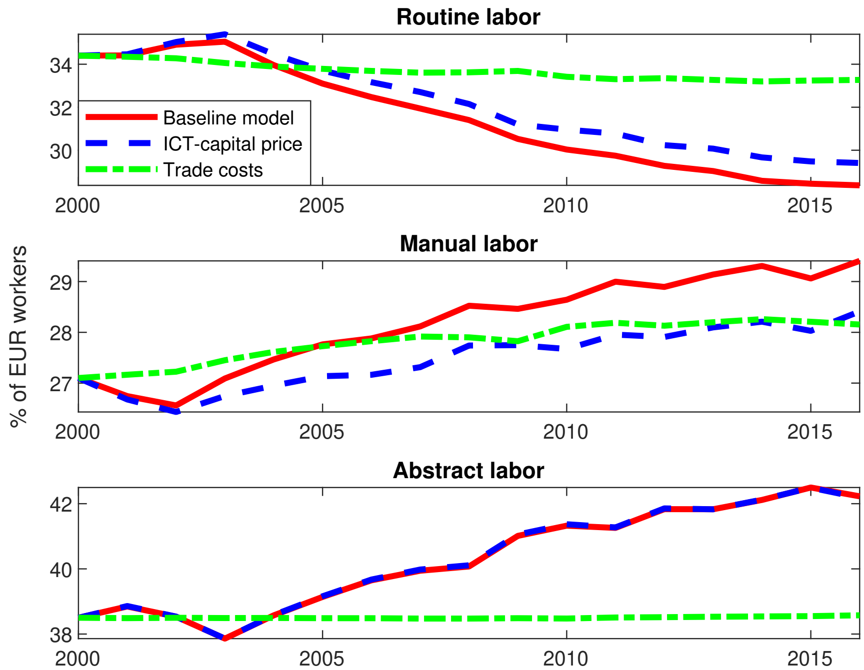
Table 2.2: Employment changes in the data and different models

	Data	**Baseline**	**ICT capital**	**Trade**
Routine	-6.61	-6.03	-4.99	-1.13
Manual	2.28	2.31	1.31	1.05
Abstract	4.33	3.72	3.68	0.07

Results are expressed in percentage point variation.

The fact that automation is the main factor of labor polarization is consistent with several empirical studies focusing on Western Europe. For instance, Michaels, Natraj, and Van

Figure 2.7: Impact of each driving force on employment dynamics



Reenen (2014) find that automation has a large influence on the decrease in routine labor and the increase in abstract labor in nine Western European countries. Similarly, Goos, Manning, and Salomons (2014) consider that automation has a much bigger influence on job polarization than offshoring. Other papers consider that the effect of automation on labor polarization is small (see Cortes, Jaimovich, and H. E. Siu (2017) and Eden and Gaggl (2018)) or that offshoring is its main driver (see Mandelman and Zlate (2021)).

Some reasons may explain those differences. First, the time period and the region of interest are different. Most of those papers study the United States and go back to the 1980s. Besides, theoretically, Mandelman and Zlate (2021) follow a different modeling strategy for the offshoring process. Only high-skill individuals offshore their work to the other country.

When trade costs diminish, some middle-skill workers become productive enough to offshore their own production and become considered high-skill (abstract) workers. Therefore, the fall of the trade cost directly causes an increase in abstract labor. This easily explains why they find that offshoring has a strong impact on the increase in the share of abstract labor and I do not. As previously explained, my modeling strategy makes more sense in the context of Western European countries. Indeed, offshoring to high-income countries mostly occurs within Western Europe and, as such, should not influence the aggregate distribution of employment in the region.

Finally, the value of the elasticity of substitution between routine and abstract workers has an impact on the results. Very different estimates have been given for this elasticity as explained in Hamermesh and Grant (1979) or Borjas, Grogger, and Hanson (2011). The choice of $\theta = 5$ provides the best fit in the context of my model but is somewhat higher than most recent estimates. However, at least two reasons may account for this need of a higher value. First, ICT capital is the only type of capital in the model. However, ICT capital actually represents a small share of the total capital stock. An underestimated share of aggregate capital should imply a higher value of θ, as indicated in Hamermesh and Grant (1979). Second, estimates are usually done using aggregates, neglecting the presence of any "exterior" type of labor. However, here, low-skill manual workers are also present in the model. As such, there is an outside option available if the number of workers supplying routine labor is not large enough. The presence of this outside option for labor is the main justification provided by Blankenau and Cassou (2011) to explain why they find higher estimates when looking at each industry's elasticity instead of the aggregate elasticity for instance.

Nevertheless, as a robustness check, I show the consequences of choosing $\theta = 2.78$ in Appendix 2.7.5 as recently estimated in Harrigan, Reshef, and Toubal (2021) for France. With this new value of θ, the capacity of the model to reproduce the exact dynamics of the shares of each type of labor somewhat diminishes although the qualitative results are unchanged. While the dynamics of the manual labor share remains very similar, the magnitude of changes of abstract and routine labor shares are lower. Here, the routine labor share falls from 34.4% to 30.3% while it drops to 28.4% in the baseline model. Besides, the abstract labor share increases from 38.5% to 40.4% while it reaches 42.2% in the baseline model. These differences are not surprising as the elasticity of substitution between ICT capital and routine labor is lower. The increase in automation remains the main factor of job polarization. Nevertheless, both its absolute and relative effects are dampened and the role of international trade is slightly magnified.

2.5.3 Welfare analysis

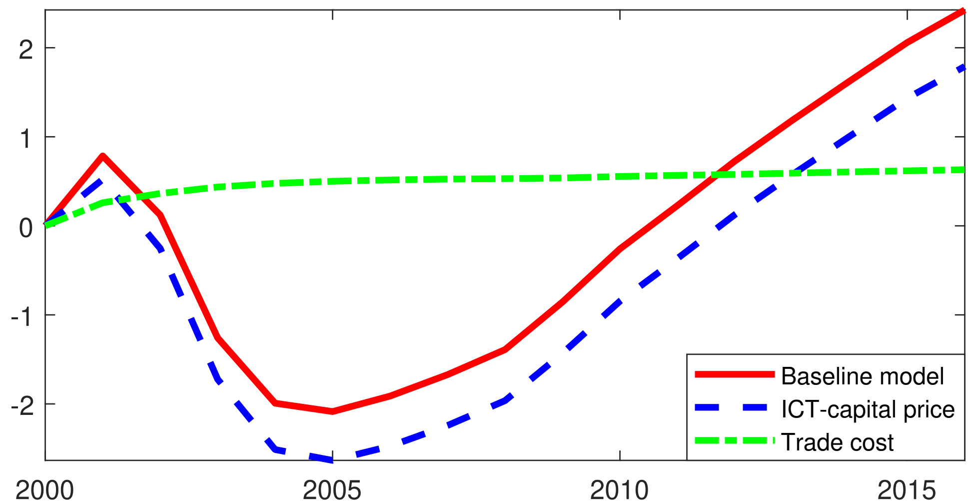
Finally, I investigate the welfare effects of a joint fall in ICT-capital prices and trade costs. This study is somewhat limited, as agents pool their income and are therefore insured against adverse shocks. Any redistributive effects are thus shut down by definition. However, the magnitude and direction of aggregate welfare changes still matter, especially in light of the ability of the model to reproduce the dynamics of the occupational distribution of employment between 2000 and 2016.

To determine the welfare consequences of both driving forces for the EUR region, I calculate the Hicksian-equivalent consumption change implied by the simulation over the 17 years. The Hicksian-equivalent change measures during T periods the percentage of permanent per-capita consumption ξ that the large family would have to lose – or gain – to be indifferent between the situation where ICT-capital prices and trade costs remain constant over the period and the situation where ICT-capital prices and trade costs decrease as in the data:

$$E_{2000} \sum_{t=2000}^{2016} \beta^t \Big[u\big((1-\xi)C_t\big)\Big] = \sum_{t=2000}^{2016} \beta^t \Big[u(C_{2000})\Big] \tag{2.72}$$

As such, it is a measure of aggregate cumulative welfare gains or losses for Western European countries. I present the welfare impact of both driving forces when they happen simultaneously or separately in Figure 2.8.

Figure 2.8: Cumulative welfare changes for different scenarios



Welfare results are expressed in percentage of cumulative per-capita EUR consumption.

First, Figure 2.8 shows that 16 years of a fall of ICT-capital prices and trade costs had a positive effect in terms of cumulative welfare. Those driving forces increased aggregate per-capita consumption by almost 2.5% over the period. However, until 2011, the cumulative effects were negative. Indeed, the unexpected fall of the price of ICT capital has a negative short-term effect on consumption. When the first "shock" occurs, the family decides to decrease consumption and investment to increase the number of individuals that train to become high-skill workers, leading to a decrease in welfare in the short run. However, having more high-skill workers causes a rise of the average wage. As such, consumption starts increasing after a few periods. As welfare gains are discounted over time, cumulative welfare becomes positive only in 2011. Despite this short-term negative impact, almost 75% of the welfare gains over the period are due to the increase in automation.

Indeed, the fall in trade costs has a much smaller impact on welfare as it has a lower effect on the dynamics of employment distribution. However, its welfare impact is positive over the whole period. The fall in trade costs causes a decrease in the marginal cost of the tradable good as more tasks are offshored and supplied at a lower cost, leading to a decrease in its price. Furthermore, the price of foreign final goods also diminishes with the decrease in trade costs. As such, consumption increases despite the fact that the rise in offshoring forces some routine workers to become manual workers and to experience a fall of their wage.

2.6 Conclusion

In this chapter, I study the role of automation, final good international trade and offshoring on the changes of the occupational distribution of employment in Western Europe between 2000 and 2016. I build a three-region general equilibrium model where Western European firms can offshore routine production to the other regions of the world or replace routine labor by machines. I use actual annual changes in ICT-capital price and trade costs as exogenous driving forces to reproduce the dynamics of automation, offshoring and trade in final goods. The model accurately reproduces the polarization of employment that occurred during the period: the share of routine labor falls while the shares of abstract and manual labor increase.

Decomposing the effects of both driving forces, I find that automation is the overwhelming factor explaining the changes in the distribution of employment. Offshoring has a small effect on routine and manual labor shares, but none on the share of abstract labor. Furthermore, international trade in final goods has almost no impact, as its level remains relatively low. Finally, conducting a welfare analysis, I find positive cumulative welfare changes in the long run but short-run losses. Most of those variations are due to automation: the boom in high-skill training lowers consumption in the short term but raises it in the long run. The increase in international trade leads to lower but always positive welfare effects as it causes a decrease in the relative price of tradable goods.

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2.7 Appendix

2.7.1 Classification of labor

Table 2.3 indicates to which types of occupations are associated abstract, routine and manual labor for the EUR and CEE regions. For those regions, I use the two-digit ISCO-08 classification from the CEDEFOP. Abstract labor is composed of the high-skill occupations as usual in the literature. Then, occupations are separated between routine and manual labor following logic and the classification work done by Goos, Manning, and Salomons (2014). Occupations with high offshorability and routine task intensities are considered as routine tasks. On the contrary, occupations with low offshorability and routine task intensities are classified as manual tasks.

For the ROW region, homogenized data at the two-digit level are not available. As such, I must use the ILO estimate of the shares for the one-digit ISCO-08 classification. In this classification, categories "6. Skilled agricultural and fishery workers" and "9. Elementary occupations" cannot be distinguished. I choose not to include them in the computation. As such, some workers that should be included are not. However, they are mostly manual workers and their impact on the employment distribution in the EUR region, which is the main concern of this chapter, should be extremely limited. The separation of occupations into the three categories is detailed in Table 2.4.

Table 2.3: Separation of occupations into abstract, routine and manual labor

Abstract Labor	
1.	Legislators, senior officials and managers
2.	Professionals
3.	Technicians and associate professionals
Routine Labor	
41.	General and keyboard clerks
42.	Customer services clerks
43.	Numerical and material recording clerks
44.	Other clerical support workers
71.	Building and related trades workers, excluding electricians
72.	Metal, machinery and related trades workers
73.	Handicraft and printing workers
74.	Electrical and electronic trades workers
75.	Food processing, wood working, garment and other craft and related trades
81.	Stationary plant and machine operators
82.	Assemblers
93.	Labourers in mining, construction, manufacturing and transport
Manual Labor	
51.	Personal service workers
52.	Sales workers
53.	Personal care workers
54.	Protective services workers
83.	Drivers and mobile plant operators
91.	Cleaners and helpers
94.	Food preparation assistants
95.	Street and related sales and service workers
96.	Refuse workers and other elementary workers

The categories are those of the International Standard Classification of Occupation (ISCO-08). The categories "0. Armed forces" which is military as well as "6. Skilled agricultural and fishery workers" and "92. Agricultural, forestry and fishery labourers" which are composed of agricultural workers are not included in the computations.

Table 2.4: Separation of occupations for the ROW region

Abstract Labor	
1.	Legislators, senior officials and managers
2.	Professionals
3.	Technicians and associate professionals
Routine Labor	
4.	Clerical support workers
7.	Craft and related trade workers
8.	Plant and machine operators and assemblers
Manual Labor	
5.	Services and sales workers

The categories are those of the International Standard Classification of Occupation (ISCO-08). The categories "0. Armed forces", "6. Skilled agricultural and fishery workers" and "9. Elementary occupations" are not included in the computations.

2.7.2 Definition of the demands for tradable goods

$$
\begin{aligned}
y_{E,t}^{E} &= \alpha_y \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} (1-\alpha_C-\alpha_r) \left(\frac{P_{T,t}}{P_{H,t}}\right)^{-\phi} (C_t + I_t) \\
y_{E,t}^{C} &= \alpha_y^C \left(\frac{P_{H,t}^C}{P_t^C}\right)^{-\rho} \alpha_E^C \frac{n^C}{n} \left(\frac{\tau_t^C P_{T,t}}{e_t^C P_{H,t}^C}\right)^{-\phi} (C_t^C + I_t^C) \\
y_{E,t}^{R} &= \alpha_y^R \left(\frac{P_{H,t}^R}{P_t^R}\right)^{-\rho} \alpha_E^R \frac{n^R}{n} \left(\frac{\tau_t^R P_{T,t}}{e_t^R P_{H,t}^R}\right)^{-\phi} (C_t^R + I_t^R) \\
y_{C,t}^{C} &= \alpha_y^C \left(\frac{P_{H,t}^C}{P_t^C}\right)^{-\rho} (1-\alpha_E^C-\alpha_R^C) \left(\frac{P_{T,t}^C}{P_{H,t}^C}\right)^{-\phi} (C_t^C + I_t^C) \\
y_{C,t}^{E} &= \alpha_y \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} \alpha_C \frac{n}{n^C} \left(\frac{\tau_t^C e_t^C P_{T,t}^C}{P_{H,t}}\right)^{-\phi} (C_t + I_t) \\
y_{C,t}^{R} &= \alpha_y^R \left(\frac{P_{H,t}^R}{P_t^R}\right)^{-\rho} \alpha_C^R \frac{n^R}{n^C} \left(\frac{\tau_t^{CR} e_t^C P_{T,t}^C}{e_t^R P_{H,t}^R}\right)^{-\phi} (C_t^R + I_t^R) \\
y_{R,t}^{R} &= \alpha_y^R \left(\frac{P_{H,t}^R}{P_t^R}\right)^{-\rho} (1-\alpha_C^R-\alpha_E^R) \left(\frac{P_{T,t}^R}{P_{H,t}^R}\right)^{-\phi} (C_t^R + I_t^R) \\
y_{R,t}^{C} &= \alpha_y^C \left(\frac{P_{H,t}^C}{P_t^C}\right)^{-\rho} \alpha_R^C \frac{n^C}{n^R} \left(\frac{\tau_t^{CR} e_t^R P_{T,t}^R}{e_t^C P_{H,t}^C}\right)^{-\phi} (C_t^C + I_t^C) \\
y_{R,t}^{E} &= \alpha_y \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} \alpha_R^E \frac{n}{n^R} \left(\frac{\tau_t^R e_t^R P_{T,t}^R}{P_{H,t}}\right)^{-\phi} (C_t + I_t)
\end{aligned}
$$

2.7.3 Data and Model presentation

Figure 2.9: Trade cost between the different regions

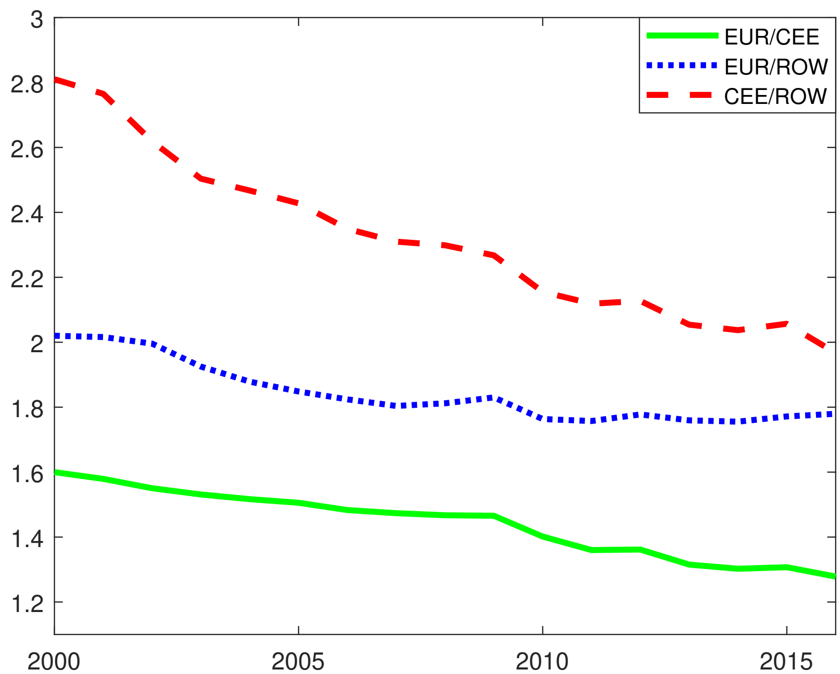


Figure 2.10: ICT-capital cost (normalized to 1 en 2000)

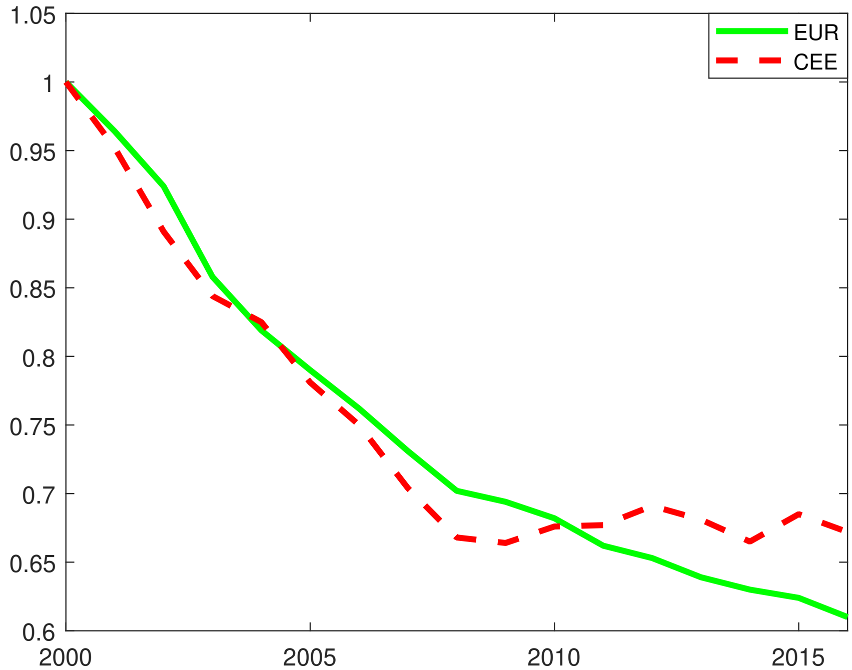
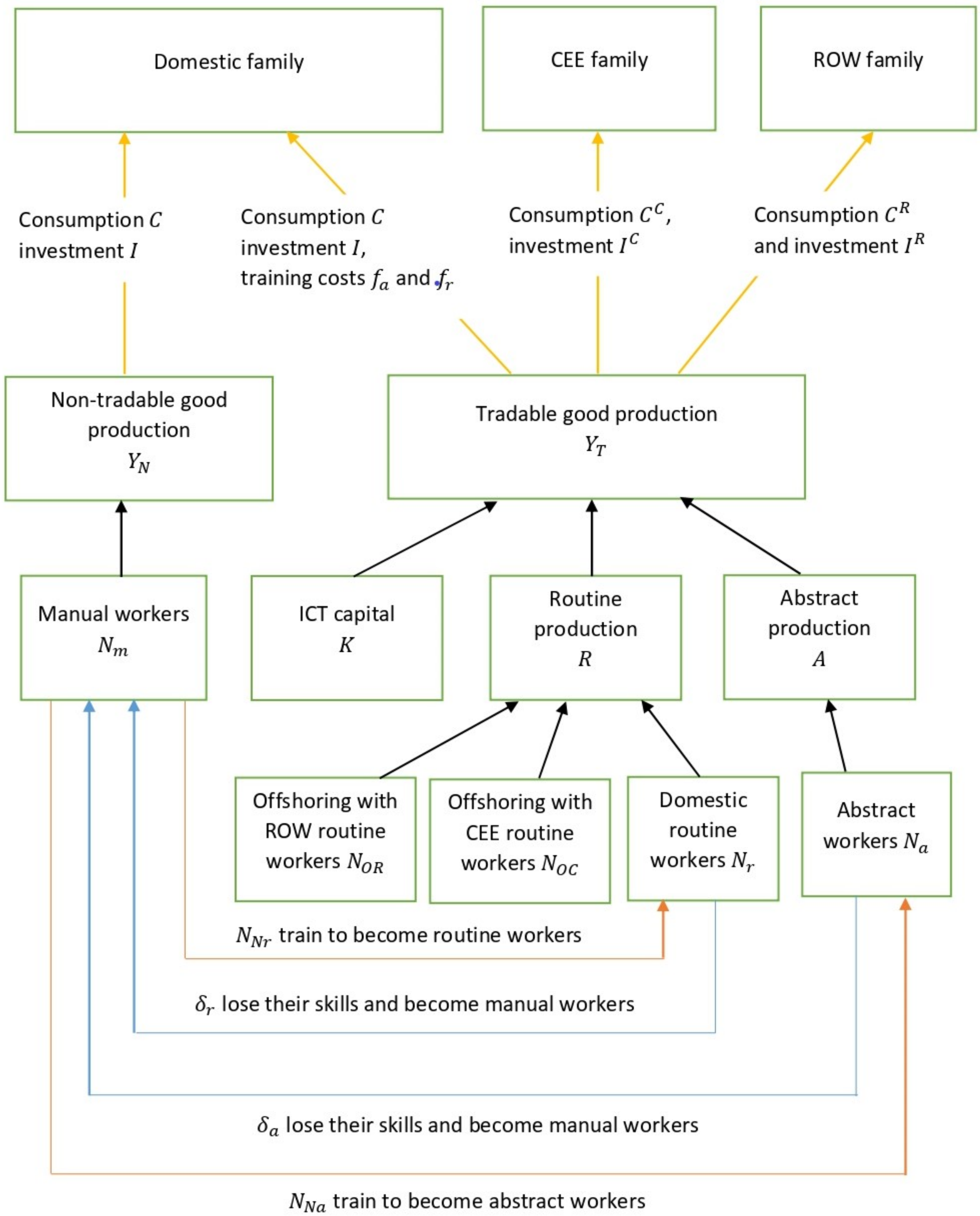


Table 2.5: Share of import or domestic demand by region of origin

	EUR	**CEE**	**ROW**
EUR	99.21%	9.39%	1.11%
CEE	0.40%	90.33%	0.03%
ROW	0.39%	0.28%	98.86%

Each row indicates the origin of products while each column indicates its destination. Results are indicated as a share of total goods in the receiving region. As such, each column sums up to 100%.

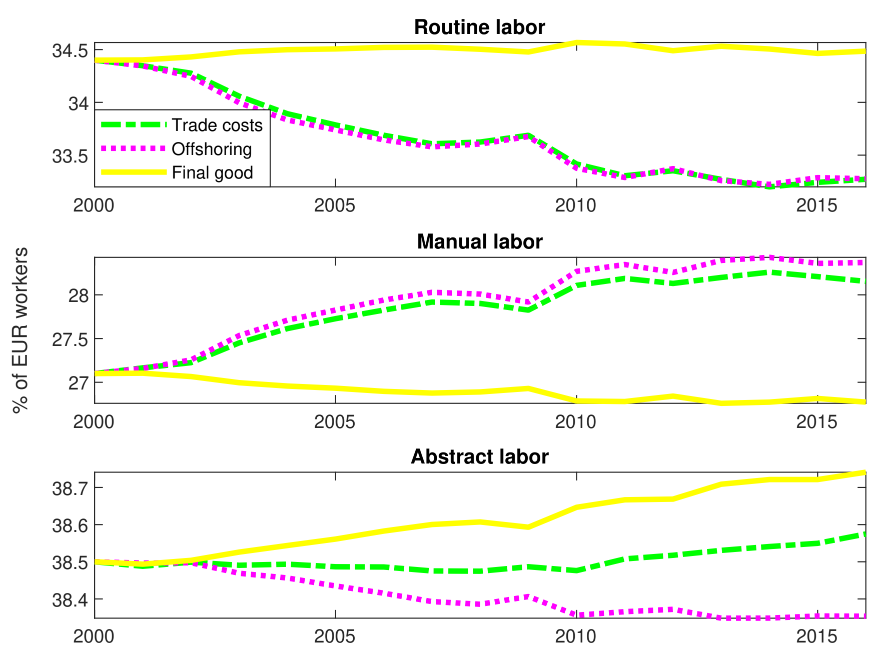
Figure 2.11: General presentation of the Model



2.7.4 Detailed trade cost impact on employment dynamics

I separate the impact of the decrease in trade costs on the dynamics of employment between the impact of offshoring and the one of trade on final goods. Figure 2.12 shows the results. As we can see, the trade of final goods has almost no impact. The decrease in the trade costs leads to a small increase in the demand of EUR goods abroad. As such, EUR tradable-good firms increase their production which causes a slight increase in the number of both routine and abstract workers. But, as international trade is very low between the EUR region and the other regions displayed in the model, this effect is extremely small. Thus, almost all changes in the distribution of employment due to the decrease in trade costs come from offshoring. That is why I focus on offshoring and not final good trade in the main part of the chapter.

Figure 2.12: Impact of each type of trade on the employment distribution

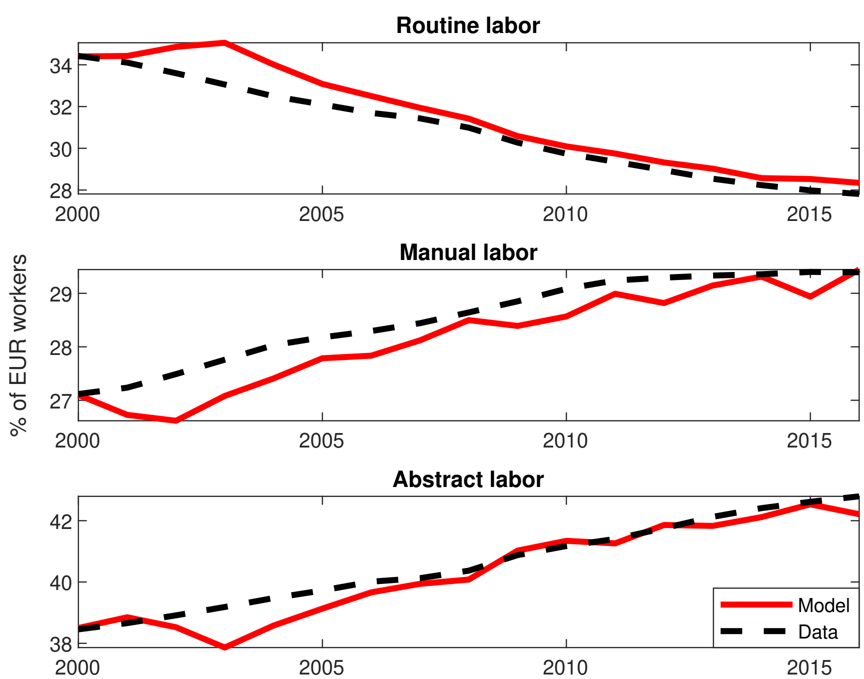


2.7.5 Robustness check

Changes in ICT-capital prices in the ROW region

Figure 2.13 shows the employment dynamics when the ROW region is subjected to the same ICT-capital price exogenous driving force as the CEE region. As we can see, the dynamics are exactly the same. This supplementary driving force has absolutely no effect on the labor dynamics in the EUR region.

Figure 2.13: Labor share dynamics with changing ICT-capital price in the ROW region



Employment dynamics when $\theta = 2.78$

Figure 2.14 shows the difference in the dynamics of employment between the baseline model and the model where the elasticity of substitution between abstract and routine labor is $\theta = 2.78$. Figure 2.15 indicates the impact of each driving force with this value of θ.

Figure 2.14: Comparison with the baseline model

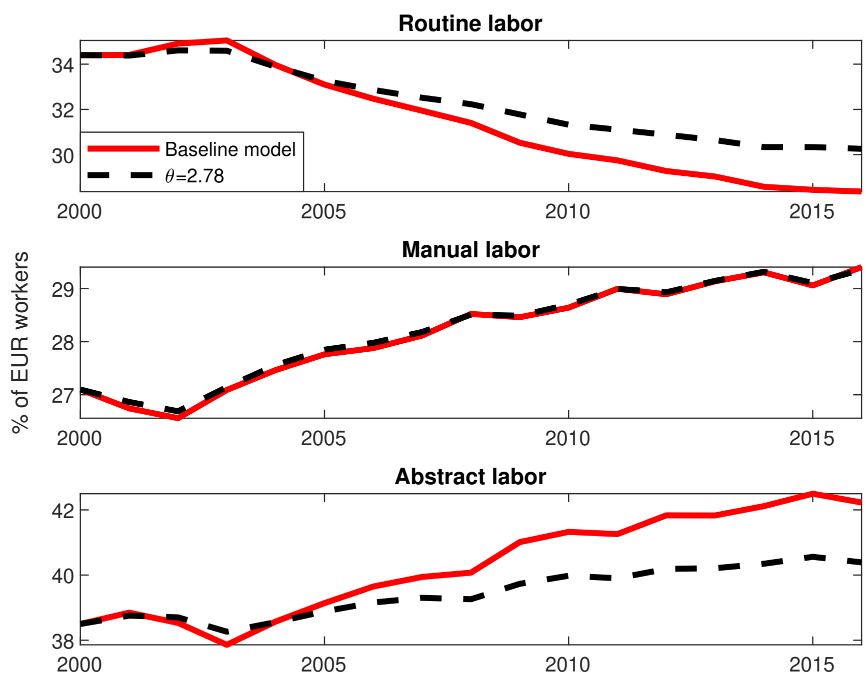
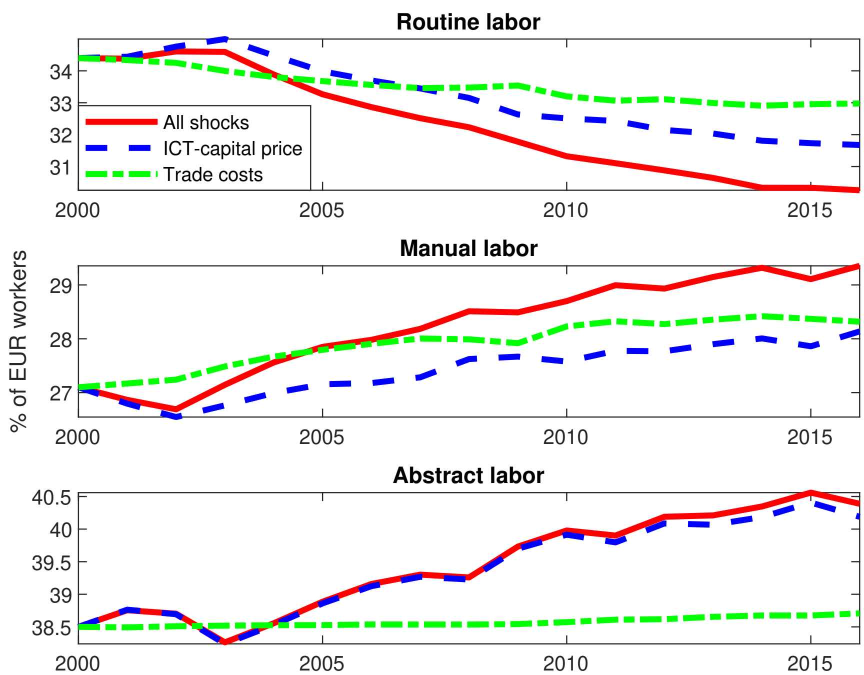


Figure 2.15: Impact of each driving force when $\theta = 2.78$



2.7.6 Model and Results with offshoring CEE firms

Model

As a robustness check, I allow CEE firms to offshore routine tasks to the ROW region. In this case, the part of the model explaining the way routine tasks are supplied for CEE firms is modified. The same modeling strategy as for EUR firms is used, but with only one offshoring category.

CEE firms can employ domestic workers or ROW workers through offshoring. Both types of workers have the same production function when working for CEE firms. Each of them supplies the effort $l_t^C = r_t^C \Lambda_t^C x_{r,t}$. Domestic workers are paid the CEE routine wage expressed in real terms $w_{r,t}^C = W_{r,t}^C / P_{T,t}$ while ROW workers earn $w_{r,t}^R T_t^{CR}$, with $T_t^{CR} = e_t^{RC} P_{T,t}^R / P_{T,t}^C$ the terms of trade between countries CEE and ROW, and $e_t^{CR} = e_t^R / e_t^C$ the nominal exchange rate between the CEE and the ROW regions. Firms incur a supplementary cost to offshore labor $F_t^{CR}(j) = \zeta^{CR}(j)\tau_t^{CR}$ with $\zeta^{CR}(j) = z^{CR}(1 + j_{max}^C)$. As such, the costs to produce a specific task domestically $c_{D,t}^C$ and to offshore it to the ROW country $c_{OR,t}^C(j)$ are expressed as follows:

$$c_{D,t}^C = \frac{w_{r,t}^C}{x_r \Lambda_t^C} \tag{2.73}$$

$$c_{OR,t}^C(j) = F_t^{CR}(j) \frac{w_{r,t}^C T_t^{CR}}{x_r \Lambda_t^C} \tag{2.74}$$

This means that a task is offshored whenever

$$c_{D,t}^C \geq c_{OR,t}^C(j) \tag{2.75}$$

I need to assume that $c_{D,t}^C \geq c_{OR,t}^C(0)$ to make sure that at least some offshoring takes place. There is only one "marginal offshoring task" $j = J_{OR,t}$ such that $c_{D,t}^C = c_{OR,t}^C(J_{OR,t})$. As workers are perfectly substitutable, this means that for all tasks $j \geq J_{OR,t}$, routine tasks are produced domestically while for $j \leq J_{OR,t}$ they are produced through offshoring. Perfect competition implies that the cost of each task is defined as follows:

$$c_t^C(i,j) = \begin{cases} c_{OR,t}^C(j) & = F_t^{CR}(j)\frac{w_{r,t}^R T_t^{CR}}{x_{r,t}\Lambda_t^C} & 0 \leq j < J_{OR,t} \\ c_{D,t}(j) & = \frac{w_{r,t}^C}{x_{r,t}\Lambda_t^C} & J_{OR,t} \leq j \leq j_{max}^C \end{cases}$$

The routine average marginal cost $mc_{r,t}(i) = mc_{r,t}$ can be expressed as the weighted average of the average cost of each type of workers:

$$mc_{r,t}^C(i) = G(J_{OR,t})mc_{OR,t}^C + \left[1 - G(J_{DC,t})\right]mc_{D,t}^C \tag{2.76}$$

with the average (marginal) cost of a domestic worker and of a worker of the ROW region expressed respectively as:

$$mc_{D,t}^C = \frac{w_{r,t}^C}{x_{r,t}\Lambda^C} \tag{2.77}$$

$$mc_{OR,t} = \frac{1}{J_{OR,t}}\int_0^{J_{OR,t}} F_{C,t}^{CR}(j)\frac{w_{r,t}^R T_t^{CR}}{x_{r,t}\Lambda^C}\, dj \tag{2.78}$$

As the monopolistic firms choose the same price, they all follow the same decision process. The total of workers supplying routine tasks for the CEE firms is $N_{f,t}^C = N_{D,t}^C + N_{OR,t}^C$ with N_{OR}^C the amount of ROW workers and $N_{D,t}^C$ the amount of domestic workers supplying routine tasks for CEE firms.

We can express the shares of each type of workers over the number of workers producing routine tasks for EUR firms as:

$$\frac{N_{OR,t}^C}{N_{f,t}^C} = G(J_{OR,t}), \qquad \frac{N_{D,t}^C}{N_{f,t}^C} = 1 - G(J_{OR,t}) \tag{2.79}$$

Finally, given the assumption of uniform distribution, we can easily define the location decision cutoffs as:

$$J_{OR,t} = j^C_{max} \frac{N^C_{OR,t}}{N^C_{f,t}} \tag{2.80}$$

We also need to modify the expression of the number of workers supplying routine tasks in the ROW region:

$$N^R_{r,t} = \left(N^R_{D,t} + \frac{n}{n^R} N_{OR,t} + \frac{n^C}{n^R} N^C_{OR,t} \right) \tag{2.81}$$

Finally, the equations of international trade for the CEE and the ROW regions become:

$$n^C N^C_{OR,t} w^R_{r,t} T^{CR}_t \frac{P^C_{T,t}}{P^C_t} + n^R y^C_{R,t} S^{CR}_t + n \frac{y^C_{E,t}}{S^C_t} = n N_{OC,t} w^C_{r,t} \frac{P^C_{T,t}}{P^C_t} + n^C \left(y^E_{C,t} + y^R_{C,t} \right) + \Gamma^C \tag{2.82}$$

$$n \frac{y^R_{E,t}}{S^R_t} + n^C \frac{y^R_{C,t}}{S^{CR}_t} = \left(n N_{OR,t} w^R_{r,t} + n^C N^C_{OR,t} w^R_{r,t} \right) \frac{P^R_{T,t}}{P^R_t} + n^R \left(y^E_{R,t} + y^C_{R,t} \right) + \Gamma^R \tag{2.83}$$

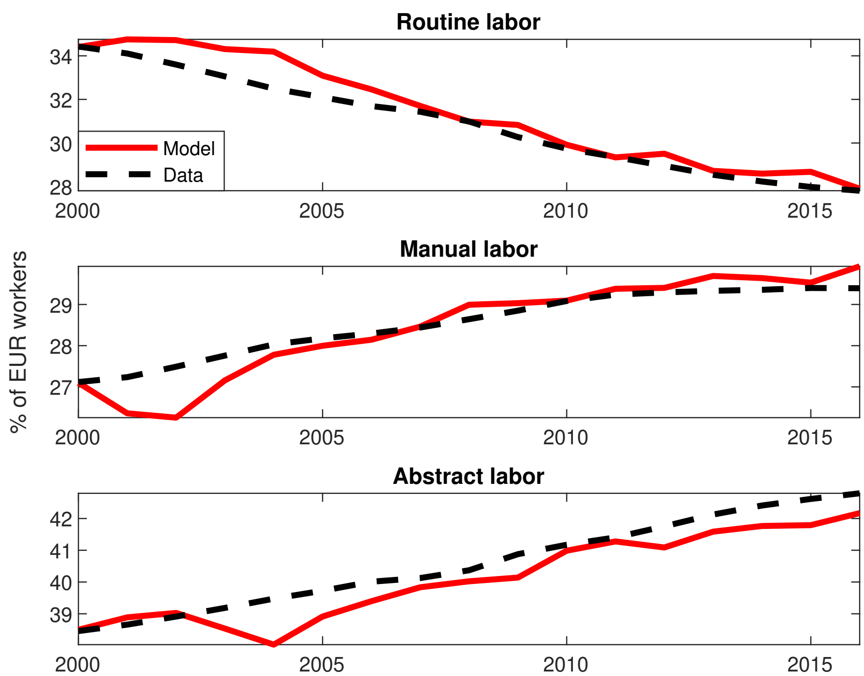
Parametrization

Following the same method as previously, I obtain that the share of offshoring between CEE and ROW regions in 2000 is $\bar{G}(J_{OR}) = 1.1\%$. Two parameters are added to the model : z^{CR} and j^C_{max}. I choose the values to best follow the dynamics of offshoring between the CEE and ROW regions in the data. I obtain: $j^C_{max} = 7$ and $z^{CR} = 1.185$.

Results

Figure 2.16 shows the dynamics of the distribution of employment when offshoring between the CEE and ROW regions is allowed. As we can see, the results are extremely similar to the baseline model. The decrease of routine labor is almost perfectly depicted while the increase of both abstract and manual labor are also well reproduced.

Figure 2.16: Dynamics of the distribution of employment



Chapter 3

Robots, Optimal Taxation and Welfare

Abstract

This chapter investigates the optimal taxation of robots. I build a general equilibrium model of a small open economy with three types of workers, ICT capital (robots), trade in final goods and endogenous offshoring. After calibrating the model to Spanish data, I compute the (dual) Ramsey optimal policy, and find that the optimal allocation implies a very large subsidy on robots, as ICT capital complements abstract (high-skill) labor and causes an increase of wages that more than compensates the displacement effect – the replacement of routine (middle-skill) workers by robots and manual (low-skill) workers. I then investigate the effects of a quantitatively more realistic subsidy on robots, which implies qualitatively similar but quantitatively attenuated results. Finally, I study the transition process implied by an exogenous decrease in the price of ICT capital – as observed in the recent data – jointly with the implementation of a subsidy on ICT capital. The transition increases welfare in the long run but not in the short run, as it amplifies the initial replacement of routine (middle-skill) employment by manual (low-skill) labor. All results are robust to a variety of model specifications.

3.1 Introduction

While machines have been replacing workers for more than two centuries, automation has been particularly present since the end of the 20th century. It has caused structural changes on the labor market in the United States and Western Europe, inducing a polarization of employment (see Autor and Dorn (2013) or Michaels, Natraj, and Van Reenen (2014)). Industrial robots and computerized machines have replaced routine middle-skill workers. Those workers have become low-skill manual workers but also abstract high-skill workers, that are required to design, build and insure that those new machines function properly. History has shown that, while potentially costly in the short-run, such a process – based on physical capital in the past – favors technical progress, makes the production process more efficient and ultimately improves life conditions especially as it decreases the price of goods (Mokyr, Vickers, and Ziebarth (2015)). However, new studies consider that with the rise of Artificial Intelligence, tasks are becoming automatable at an accelerating pace (Brynjolfsson and McAfee (2014), Ford (2015)). For example, almost half of the jobs may disappear or have their content strongly modified by 2030 in the United States (Frey and Osborne (2017)). Therefore, it may be difficult to create enough new jobs to compensate the increasing speed of automation. As such, the positive relation between automation and life conditions is now questioned. Considering the large consequences of automation on labor markets, it is of great interest to understand what is the level of automation that maximizes social welfare.

This chapter contributes to the debate by studying in details the welfare consequences of taxes/subsidies on robots in a small open economy. This idea of taxing robots has notably been proposed by Bill Gates[1] and has been discussed in the European Parliament (see Delvaux (2016)). This would lead to an increase of the price of Information, Communication

[1] Kevin J. Delaney, "The robot that takes your job should pay taxes, says Bill Gates, "Quartz, February 17, 2017, https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/.

and Technological (ICT) capital.[2] As such, it would diminish its use and its effects on labor market. However, as robots tend to increase the productivity and are complement with high-skill workers, increasing automation may actually increase the employment of firms that automate (see Acemoglu, Lelarge, and Restrepo (2020) for France or Dixon, Hong, and Wu (2021) for Canada) and even aggregate employment, as new evidence seems to indicate for Spain (Koch, Manuylov, and Smolka (2021)) or France (Aghion et al. (2020)). In this case, a subsidy on robots would actually increase welfare.

To answer this question, I build a general equilibrium model with a small open economy that is a simplified version of the model developed in Maillard (2021). I include three types of workers to account for labor-market polarization: high-skill workers supply abstract labor and middle-skill workers provide routine labor to produce an internationally tradable good with ICT capital. Low-skill workers supply manual labor to produce a non-tradable good. Individuals have to train to become either high or middle-skill workers and obtain a higher wage but skills are randomly destroyed every period. I assume that ICT capital and abstract labor are relative complements while ICT capital and routine labor are relative substitutes. In addition, firms can offshore the production of routine tasks to a sub-region of the Rest of the World (representing Central and Eastern European countries and developing Asian countries). The amount of offshored labor depends on the relative wage and two costs: the trade cost and an "offshorability" cost that varies depending on the task. The government pays for its exogenous spending by levying distortionary taxes on labor and ICT capital. Before looking at the Ramsey-optimal taxation, I carefully parametrize the model so that the steady state without a tax on ICT capital replicates key characteristics of Spain in 2016 while the Rest of the World is considered as exogenous. I focus on Spain as a representative small open economy of the Euro Area that has experienced a strong labor-market polarization over the last two decades as well as a strong drop of the price

[2] In this chapter, I use the notions of robot and ICT capital interchangeably to include all capital classified as computing equipment, communication equipment, and computer software and databases.

of ICT capital. As a first exercise, I compute the Ramsey-optimal policy (Ramsey (1927)) using robot taxation as the only instrument – government spending is exogenous and the labor tax balances government's budget – and study the impacts of such a policy under various alternative assumptions. I find very large and negative tax rates on robots, *i.e.* robots should be subsidized almost as much as possible. Second, I look at the consequences of implementing a more realistic subsidy of 50%. Finally, I examine the transitional effects of implementing this subsidy together with a downward-trending price of ICT capital.

First, when computing the Ramsey-optimal plan, I find that it is welfare maximizing to implement a very large subsidy on robots, around 6,312 – 631,200%. This result is due to the small size of ICT-capital income compared with labor income and the fact that all income is equally shared among members of the large family. As such, it is optimal to have a net rate of return of ICT capital that almost equals zero and to pay the small resulting labor tax to reap the welfare benefits of the subsidy on robots. The latter leads to a decrease of ICT-capital price and, therefore, to a rise of automation. The complementarity of robots with astract labor leads to an increase in the number of high-skill workers while the substitutability with routine labor causes a reduction in the number of middle-skill workers. The share of manual (low-skill) workers also slightly increases as a consequence. Furthermore, the drop in the price of robots leads to an increase in the demand for the tradable good both domestically and abroad. This causes an endogenous rise of productivity. As such, routine and abstract wages increase, with a stronger impact for the abstract wage. Consumption increases as prices decrease and (aggregate) wage increases. Finally, labor supply only slightly decreases due to the 2.4pp rise in the labor tax. As consumption rises and the disutility of labor diminishes, welfare increases. However, from a quantitative perspective, these changes in welfare are quite small. These results are surprisingly robust to alternative parameter values and to alternative model assumptions, such as inelastic labor supply, positive government spending, complete international financial markets, sectoral mobility costs or unemployment.

Second, as the level of the Ramsey-optimal subsidy on robots is highly unrealistic, I investigate the welfare consequences of implementing a 50% subsidy. In this case, welfare gains are about a third of the Ramsey-optimal welfare gains. Key variables values and transmission mechanisms are similar to those featured in the Ramsey-optimal subsidy, but the magnitude of the variations is reduced. The labor-market polarization occurs while wages, consumption and output increase. Those results are consistent with those found in Humlum (2019) for another European country (Denmark).

Third, I find that a 5% yearly ICT-capital price decrease – along with a zero tax on robots – leads to an increase of welfare of around 1.1% of permanent consumption over a fifteen-year period. Welfare changes are always positive during the transition process but welfare decreases for a few periods after its initial increase. With the first unexpected price decrease, consumption and abstract training rise at the expense of investment in ICT capital. However, this temporary decrease of investment leads to a fall of capital gains and of the number of abstract workers in the following period. Only after a few years, the decrease of ICT-capital price leads to the expected rise of output, wages, consumption and thus welfare. Conditional on this path of ICT-capital price, implementing a 50% subsidy on robots causes higher welfare changes with gains of about 1.35% of permanent consumption over the period. Nevertheless, gains are lower in the short run. Indeed, the subsidy causes a higher increase of manual workers at the expense of better paid routine workers. This causes a decrease of the average wage. However, after a few periods, as the subsidy causes a higher decrease in the ICT-capital cost for the large family, abstract labor increases more. Besides, the higher demand for tradable goods leads to a higher increase in output, wages, consumption and thus welfare. This main result is also robust to alternative model specifications.

The chapter is organized as follows. Section 2 reviews the related literature and highlights the contributions of the chapter. Section 3 details the model. Section 4 explains the parametrization. Section 5 presents the main results. Section 6 concludes.

3.2 Literature review

Optimal taxation problems are as old as the seminal work of Ramsey (1927). But his results were mostly forgotten for decades. Only in the 1980s, Judd (1985) and Chamley (1986) came up with an important result concerning the optimal level of capital taxation using the maximization problem defined in Ramsey (1927). They find that capital taxation should always be equal to zero in the steady-state while labor taxation should be positive in a simple representative-agent model. However, several papers show that this result does not necessarily hold with more complex models. For example, Jones, Manuelli, and Rossi (1997) find that it may be optimal to have positive capital taxation if the government cannot distinguish workers of different skills. This problem of capital taxation with workers of different skill levels is the main point of interest for this chapter.

Almost two decades later, Angelopoulos, Asimakopoulos, and Malley (2015) look at optimal taxation using the Ramsey set-up in a representative-agent model with capital-skill complementarity. Allowing for a large choice of instruments, they find that training to become high-skill should be subsidized while the presence of a capital tax depends again on whether the government is able to discriminate between skilled and unskilled workers. Tsai, Yang, and Yu (2018) use a similar model but with heterogeneous agents and actual dynamics of the price of capital. Here, the tax on capital should also be positive only if a progressive tax on labor is not possible. However, this result stems from redistributive concerns. As capital is complementary with skilled labor, taxing capital has the same function as a progressive tax on labor. Using a task-based model, Acemoglu, Manera, and Restrepo (2020) find that at optimum, capital and labor tax rates should be equal to avoid any supplementary distortion. However, if automation is too strong, increasing the taxation of robots is optimal as it increases employment. They conclude that increasing taxes on robots could increase employment up to 4% in the United States. Their results differ from those of this chapter as their model is built to consider that automation has a negative effect on the employment level of a country. While the effect of automation on labor demand remains debated, this hypothesis seems in contradiction with some of the latest empirical findings based on European data (*e.g.* see Aghion et al. (2020)).

Other papers have used the Mirrleesian approach (Mirrlees (1971)) to obtain the optimal capital taxation level with capital-skill complementarity. Slavik and Yazici (2014) build an heterogeneous-agent model with two types of agents with different permanent skill levels. They find that capital that is complementary with skilled labor should be taxed 27 percentage points higher than capital that is skilled-neutral. Guerreiro, Rebelo, and Teles (2017) use a similar model but with an overlapping generation setup. Workers choose between the two possible skill levels when they enter the labor force. They find that the decrease in the price of automation leads to an increase in inequalities and a fall in welfare. As such, they conclude that robots should be taxed until the initial workers retire and all new workers choose to be high skilled. Then, Costinot and Werning (2018) find that the optimal robot tax ranges from 1% to 3.7% in the United States depending on the other tax instruments used. However, they also uncover that as robots become better in terms of technology, this tax should actually decrease. Indeed, wages become less responsive to the price of machines and the demand for machines becomes more elastic. Finally, Thuemmel (2018) finds rather similar results in a general equilibrium model with three types of occupations. With a calibration to match characteristics of the United States, he obtains that a small robot tax would be optimal in terms of welfare. It raises inequalities between routine and manual workers but diminishes inequalities between abstract and routine workers. It is the only work to consider three types of occupations, as in the present chapter. By considering labor-market polarization, they obtain lower capital tax rates than Guerreiro, Rebelo, and Teles (2017). In any case, in those four papers, the conclusions of a positive optimal taxation of robots arise from the redistributive concerns inherent to the heterogeneous-agent setup, that are not present in the present model.

Others types of models were developed in the last few years to study the consequences of the implementation of a robot tax. Using a Schumpeterian growth model, Chu et al. (2018) find that an increase of automation thanks to public subsidies causes an increase of welfare for high-skill workers and capital holders while it decreases the welfare of low-skill workers. Gasteiger and Prettner (2017) uncover that in a simple overlapping generation model – in contrary to a simple representative-agent model – automation cannot lead to long-term growth as it depresses wages. Taxing automation improves the steady-state but does not imply long-term growth. Zhang (2019) uses the canonical specific-factor framework with two types of workers and automation. He concludes that robot taxation reduces wage inequalities between both types of workers including when a labor union regulates wage levels.

Finally, Humlum (2019) is the only paper to develop a framework to focus on robot taxation in a European country. He finds that a permanent tax on robot adoption of 30% would decrease the number of firms adopting robots by 5 percentage points in a 10-year projection for Denmark. It would also lead to a small decrease of aggregate welfare but would benefit old workers in the manufacturing sector. However, he is not interested in the level of an optimal subsidy and relies more clearly on an empirical setting.

Thus, the present chapter adds to the existing literature by providing a thorough study of taxation/subsidy of robots in a general equilibrium model that takes into account labor-market polarization, offshoring and is specifically calibrated for a European country. It looks at Ramsey-optimal plans with a balanced budget, investigates the welfare effects of a more realistic subsidy but also considers the transitional dynamics produced by such a subsidy when the price of ICT capital is also decreasing, as it has been the case over the last decades.

3.3 Model

3.3.1 General presentation

The model is a simplified version of the framework developed in Maillard (2021) that builds on models from Ottaviano, Peri, and Wright (2013) and Mandelman and Zlate (2021). It features a small open economy (Home country) and the Rest of the World. The Home country has three types of workers: high-skill workers who acquire the ability to supply abstract tasks through training, middle-skill workers who acquire the ability to supply routine tasks through training, and low-skill workers who supply manual non-routine tasks. Some high and middle-skill workers randomly lose their skills at every period. Manual labor is used to produce non-tradable goods while abstract and routine labor are combined with ICT capital to produce an internationally tradable good. For simplicity, I abstract from non-ICT capital. ICT capital is of great interest as it is complement with abstract labor but substitute with routine labor. Routine tasks can be performed at home or offshored depending on their marginal cost. A government pays for its spending thanks to taxes on labor and ICT capital. Given my focus on structural change, I assume financial autarky. As both countries have different sizes, variables are presented per-capita. In the following paragraphs I present the details of the model from the perspective of the Home country. When needed, variables of the Rest of the World, that evolve exogenously, are expressed with a F superscript.

3.3.2 Households

In the small open economy, there is a large family made of a continuum of n individuals.[3] All members of the family pool their income to achieve the same level of individual consumption as in Merz (1995). This way they insure themselves against income fluctuations. Family members derive utility from consumption C_t and disutility from labor N_t. The family head

[3]There are $1-n$ individuals in the Rest of World.

thus maximizes the utility $u(C_t, 1 - N_t)$:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t) - \chi \frac{N_t^{1+\zeta}}{1+\zeta} \right] \tag{3.1}$$

with ζ the inverse of the Frisch elasticity and χ the weight of the disutility of labor. The budget constraint of the family is:

$$\begin{aligned} &(1-\tau_w)W_{m,t}N_t + \eta_t N_{r,t} + \pi_t N_{a,t} + \big[(1-\tau_k)R_{k,t} + \tau_k \delta_k/\epsilon_{K,t}\big] K_t \\ &= P_t(C_t + I_t) + f_{Na,t}N_{Na,t} + f_{Nr,t}N_{Nr,t} \end{aligned} \tag{3.2}$$

Sources of income are presented on the left-hand side while uses of this income are on the right-hand side. On the LHS, I separate income due to the work effort from the premium coming from supplying routine or abstract work. Total net raw labor income is $(1-\tau_w)W_{m,t}N_t$. This corresponds to a unit base wage $W_{m,t}$ taxed at a rate τ_m multiplied by the number of workers N_t. Low-skill workers $N_{m,t}$ supply manual labor. They only receive the base net wage $(1-\tau_w)W_{m,t}$ for their production. Each middle-skill worker supplying heterogeneous routine tasks $N_{r,t}$ earns a positive net premium η_t over the base wage due to their training. High-skill workers supplying abstract labor $N_{a,t}$ earn the base wage plus a net premium π_t that comes from their training and that is higher than the routine premium. The family earns a gross return $R_{k,t}$ per unit of ICT capital K_t that is taxed at rate τ_k. Besides, δ_K is the depreciation rate of capital and $(\epsilon_{K,t})^{-1}$ the relative cost of ICT capital with respect to the price of consumption goods that varies exogenously. On the RHS, the family consumes the final good C_t or invest in capital I_t at price P_t. Finally, it may decide to train low-skill workers to become middle or high-skilled. It must pay the sunk cost $f_{Na,t}$ to train $N_{Na,t}$ individuals to become high-skill workers. The latter cost is expressed in terms of raw labor: $f_{Na,t} = f_{Na}W_{m,t}$. Those workers become immediately productive to supply the abstract task. Each period, a share δ_a of high-skill workers sees their set of skills become obsolete, and becomes low-skill workers. Similarly, the family decides to train $N_{Nr,t}$

new middle-skill workers who become immediately productive to supply routine tasks. To this end, the family pays the sunk cost $f_{Nr,t} = f_{Nr}W_{m,t}$. As for abstract workers, a share δ_r of middle-skill workers sees their set of skills become obsolete, and becomes low-skill workers at each period. As such, the laws of motion for high-skill and middle-skill workers are respectively:

$$N_{a,t} = (1-\delta_a)N_{a,t-1} + N_{Na,t} \tag{3.3}$$

$$N_{r,t} = (1-\delta_r)N_{r,t-1} + N_{Nr,t} \tag{3.4}$$

Therefore, low-skill workers $N_{m,t}$ have the following law of motion:

$$N_{m,t} = N_{m,t-1} - N_{Na,t} - N_{Nr,t} + \delta_a N_{a,t-1} + \delta_r N_{r,t-1} \tag{3.5}$$

To sum up, the total number of workers N_t is the sum of high-skill workers supplying abstract labor $N_{a,t}$, middle-skill workers supplying routine labor $N_{r,t}$ and low-skill workers supplying manual labor $N_{m,t}$:

$$N_t = N_{a,t} + N_{r,t} + N_{m,t} \tag{3.6}$$

ICT capital follows a law of motion that includes the relative price of capital:

$$K_{t+1} = (1-\delta_K\big)K_t + \epsilon_{K,t}I_t \tag{3.7}$$

First-order conditions with respect to C_t, N_t $N_{a,t}$, $N_{r,t}$, K_{t+1} and I_t imply:

$$(1-\tau_w)\frac{W_{m,t}}{P_t} = \chi N_t^{\zeta} C_t \tag{3.8}$$

$$\lambda_t = \beta E_t \left\{ \frac{(1-\tau_k)R_{k,t+1} + \tau_k \delta_k / \epsilon_{K,t+1}}{P_{t+1}C_{t+1}} + \lambda_{t+1}(1-\delta_k) \right\} \tag{3.9}$$

$$\lambda_t = \frac{1}{\epsilon_{K,t} C_t} \tag{3.10}$$

$$f_{Na,t} = \pi_t + \beta E_t \left\{ (1-\delta_a) \frac{P_t C_t}{P_{t+1}C_{t+1}} f_{Na,t+1} \right\} \tag{3.11}$$

$$f_{Nr,t} = \eta_t + \beta E_t \left\{ (1-\delta_r) \frac{P_t C_t}{P_{t+1}C_{t+1}} f_{Nr,t+1} \right\} \tag{3.12}$$

where λ_t is the Lagrange multiplier associated with the law of motion of ICT capital. Equation (3.8) indicates the standard labor supply, equations (3.9) and (3.10) give the standard choices for capital and investment. Finally, equations (3.11) and (3.12) show that the sunk cost of training must be equal to the expected discounted sum of the net premiums, taking into account that skills can become obsolete at each period.

Per-capita consumption and investment are defined as Armington aggregators of tradable and non-tradable goods:

$$\nu_t = \left[(\alpha_y)^{\frac{1}{\rho}} (\nu_{H,t})^{\frac{\rho-1}{\rho}} + (1-\alpha_y)^{\frac{1}{\rho}} (\nu_{N,t})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \tag{3.13}$$

with $\nu = \{C, I\}$. Variables $\nu_{H,t}$ and $\nu_{N,t}$ respectively stand for the quantities of tradable and non-tradable goods in the bundle and ρ is the elasticity of substitution between tradable and non-tradable goods. Tradable-good quantities $\nu_{H,t}$ are themselves a bundle:

$$\nu_{H,t} = \left[(\alpha_h)^{\frac{1}{\phi}} (\nu_{T,t})^{\frac{\phi-1}{\phi}} + (1-\alpha_h)^{\frac{1}{\phi}} (\nu_{T,t}^F)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \tag{3.14}$$

where $\alpha_h \in [0,1]$ captures the preference for Home goods. it depends on the openness parameter μ and the size of the Rest of the World $1-n$ as follows: $(1-\alpha_h) = (1-n)\mu$. Variables $\nu_{T,t}$ and $\nu^F_{T,t}$ respectively denote the per-capita quantities of Home and Foreign varieties of tradable goods consumed in the Home country. Parameter ϕ is the trade elasticity between those tradable goods. The aggregate price index is given by:

$$P_t = \Big[\alpha_y (P_{H,t})^{1-\rho} + (1-\alpha_y)(P_{N,t})^{1-\rho}\Big]^{\frac{1}{1-\rho}} \tag{3.15}$$

where $P_{N,t}$ is the price index of the non-tradable good and $P_{H,t}$ the consumer price index of tradable goods given by:

$$P_{H,t} = \Big[\alpha_h (P_{T,t})^{1-\phi} + (1-\alpha_h)(e_t P^F_{T,t})^{1-\phi}\Big]^{\frac{1}{1-\phi}} \tag{3.16}$$

where $P_{T,t}$ and $P^F_{T,t}$ denote the producer price indices of the tradable goods respectively from the Home and Foreign countries and e_t is the nominal exchange rate with the Rest of the World. Optimization gives the following demand functions in the Home country for the non-tradable good, the Home-produced and Foreign-produced tradable goods respectively:

$$\nu_{N,t} = (1-\alpha_y)\left(\frac{P_{N,t}}{P_t}\right)^{-\rho} \nu_t \tag{3.17}$$

$$\nu_{T,t} = \alpha_y \alpha_h \left(\frac{P_{T,t}}{P_{H,t}}\right)^{-\phi} \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} \nu_t \tag{3.18}$$

$$\nu^F_{T,t} = \left(\frac{\alpha_y(1-\alpha_h)}{1-n}\right)\left(\frac{e_t P^F_{T,t}}{P_{H,t}}\right)^{-\phi} \left(\frac{P_{H,t}}{P_t}\right)^{-\rho} (n\nu_t) \tag{3.19}$$

3.3.3 Production

Tradable-good production

Perfectly competitive firms produce a tradable final good combining abstract tasks, routine tasks and ICT capital. As in Maillard (2021), the production function is the following:

$$Y_{T,t} = \left\{ \alpha_r^{\frac{1}{\theta}} R_t^{\frac{\theta-1}{\theta}} + (1-\alpha_r)^{\frac{1}{\theta}} \left[\alpha_k^{\frac{1}{\sigma}} K_t^{\frac{\sigma-1}{\sigma}} + (1-\alpha_k)^{\frac{1}{\sigma}} A_t^{\frac{\sigma-1}{\sigma}} \right]^{(\frac{\sigma}{\sigma-1})(\frac{\theta-1}{\theta})} \right\}^{\frac{\theta}{\theta-1}} \tag{3.20}$$

with $\theta > \sigma > 0$. A_t is the amount of abstract input supplied by high-skill workers and R_t is the routine input provided by domestic middle-skill workers or by Foreign middle-skill workers through offshoring for firms of the Home country. The elasticity of substitution between capital and routine labor θ is assumed to be larger than the elasticity of substitution between capital and abstract labor σ. Hence, ICT capital is a relative complement to abstract labor and a relative substitute to routine labor. Due to perfect competition, we have:

$$Y_{T,t} - r_{k,t}K_t - mc_{a,t}A_t - mc_{r,t}R_t = 0 \tag{3.21}$$

where $mc_{a,t}$ and $mc_{r,t}$ are the real marginal costs of abstract and routine tasks to be defined below and $r_{k,t} = R_{k,t}/P_{T,t}$ is the real cost of capital for firms in terms of the tradable-good price. Optimization gives the following factor demands:

$$R_t = \alpha_r \left(\frac{mc_{r,t}}{mc_{T,t}} \right)^{-\theta} Y_{T,t} \tag{3.22}$$

$$A_t = (1-\alpha_r)(1-\alpha_k) \left(\frac{mc_{a,t}}{mc_{ka,t}} \right)^{-\sigma} \left(\frac{mc_{ka,t}}{mc_{T,t}} \right)^{-\theta} Y_{T,t} \tag{3.23}$$

$$K_t = (1-\alpha_r)\alpha_k \left(\frac{r_{k,t}}{mc_{ka,t}} \right)^{-\sigma} \left(\frac{mc_{ka,t}}{mc_{T,t}} \right)^{-\theta} Y_{T,t} \tag{3.24}$$

where $mc_{ka,t} = \left[\alpha_k r_{k,t}^{1-\sigma} + (1-\alpha_k) mc_{a,t}^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$ and $mc_{T,t} = MC_t/P_{T,t}$ is the real marginal cost of the tradable good. Due to perfect competition, $MC_t = P_{T,t}$. As such, $mc_{T,t} = 1$.

Abstract tasks

High-skill workers are perfect substitutes between each others and provide abstract tasks used in the production of the tradable good with the same productivity. Abstract labor is the only input required for the production of abstract tasks, defined as:

$$A_t = N_{a,t} x_{a,t} \tag{3.25}$$

The variable $x_{a,t} > 1$ tracks the relative productivity of abstract workers. The converse variable for manual labor x_m is normalized to one. Therefore, it can be seen as the productivity differential between abstract and manual labor. Abstract workers are paid a gross real wage $w_{a,t} = W_{a,t}/P_{T,t}$. Therefore, the marginal cost of the abstract production is equal to the abstract wage divided by the productivity differential variable:

$$mc_{a,t} = \frac{w_{a,t}}{x_{a,t}} \tag{3.26}$$

Finally, the net premium π_t is the difference between the net income earned by abstract workers and their net income if they had instead supplied manual tasks:

$$\frac{\pi_t}{P_{T,t}} = (1 - \tau_w)(w_{a,t} - w_{m,t}) \tag{3.27}$$

Routine tasks

General presentation. Routine input is composed of non-substitutable routine tasks indexed by j. Those tasks follow a uniform distribution on the interval $[0, j_{max}]$ with c.d.f. $G(\cdot)$. Each routine task j can be supplied by any middle-skill worker with the same productivity, domestically or through offshoring. Index j has no influence for domestic workers, but it indicates the complexity to offshore a specific task. As such the offshoring cost depends on j. As the two types of workers are perfectly substitutable for any routine task, firms choose the factor of production with the lowest marginal cost.

Input requirements are considered identical for each firm. I consider that when offshoring firms open a subsidiary in the foreign region and give Foreign workers access to the same technology as domestic workers. This means that Foreign workers supplying routine labor for firms of the Home country have the same productivity as domestic routine workers in the Home country. Thus, the routine input is produced according to the following production function:

$$R_t = N_{f,t} x_{r,t} \tag{3.28}$$

where $N_{f,t}$ is the number of routine workers in Home firms and $x_{r,t}$ tracks the difference of productivity between routine and manual labor. As explained before, the index j has no influence on the productivity of workers and therefore does not appear in the production function. However, the index is necessary for the expression of the companion price index as the cost of a task depends on the location of the worker:

$$mc_{r,t} = \int_0^{j_{max}} c_{r,t}(j) dj \tag{3.29}$$

with $c_{r,t}(j)$ the cost of task j in Home firms. Firms pay domestic workers the identical gross real wage $w_{r,t} = W_{r,t}/P_{T,t}$ that takes into account the premium due to training. We can simply obtain the net premium η_t earned by each domestic routine worker expressed in real terms as the difference in terms of net income between what they earn and what they would have earned if employed to supply manual tasks:

$$\frac{\eta_t}{P_{T,t}} = (1 - \tau_w)(w_{r,t} - w_{m,t}) \tag{3.30}$$

Offshoring. Offshoring is done with a sub-region of the Rest of World that has a lower income level.[4] When offshoring, firms pay workers the amount they would have earned if employed by their national firms to supply routine tasks. Indeed, all routine workers of a same region are identical and the difference in productivity is simply due to the difference in the firms' technology. Therefore, a Foreign worker is paid a wage $w_{r,t}^F T_t$ when employed by Home firms, with $T_t = e_t P_{T,t}^F / P_{T,t}$ the terms of trade.

Firms have to pay a supplementary cost $F(j) = \zeta(j)\tau$ with τ an exogenous iceberg trade cost paid for each task produced abroad. This iceberg cost takes into account all types of costs to be paid when trading in another region such as trade barriers but also transportation and administrative costs. The variable $\zeta(j) = z(1+j)$ is a task-specific cost that increases with the index j: the higher j, the more complex to offshore the task, and thus the higher the offshoring cost. A high j indicates for example the importance of knowing the firm home language or its culture to perform the task. It may also illustrates that the skills required to perform the task are absent in the region and workers must be trained to perform it.

Location decisions. Given the above assumptions, the costs to produce a specific task domestically $c_{D,t}(j) = c_{D,t}$, or to offshore it $c_{OF,t}(j)$ are expressed as follows:

$$c_{D,t} = \frac{w_{r,t}}{x_{r,t}} \tag{3.31}$$

$$c_{OF,t}(j) = F(j)\frac{w_{r,t}^F T_t}{x_{r,t}} \tag{3.32}$$

The assumption of perfect substitution means that a task is offshored rather than produced domestically whenever:

$$c_{D,t} \geq c_{OF,t}(j) \tag{3.33}$$

To insure that some offshoring takes place, we need to assume that $c_{D,t} > c_{OF,t}(0)$. This

[4] It is calibrated to represent offshoring with Central and Eastern Europe and the main developing countries in Asia. For simplicity, I consider that offshoring with developed country is mostly symmetric and as such should not have an important impact for the distribution of employment and the main results.

gives us a “marginal offshored task” $j = J_{OF,t}$ such that

$$c_{D,t} = c_{OF,t}(J_{OF,t}) \tag{3.34}$$

The cost of each task is defined as follows for Home firms:

$$c_t(j) = \begin{cases} c_{OF,t}(j) & = F(j)\frac{w^F_{r,t}T_t}{x_{r,t}} & 0 \leq j < J_{OF,t} \\ c_{D,t} & = \frac{w_{r,t}}{x_{r,t}} & J_{OF,t} \leq j < j_{max} \end{cases}$$

The routine average marginal cost $mc_{r,t}$ can be expressed as the weighted average of the (average) cost of each type of workers:

$$mc_{r,t} = G(J_{OF,t})mc_{OF,t} + \big[1 - G(J_{OF,t})\big]mc_{D,t} \tag{3.35}$$

with the average (marginal) cost of a domestic worker and a foreign worker expressed respectively as:

$$mc_{D,t} = \frac{w_{r,t}}{x_{r,t}} \tag{3.36}$$

$$mc_{OF,t} = \frac{1}{J_{OF,t}} \int_0^{J_{OF,t}} F(j)\frac{w^F_{r,t}T_t}{x_{r,t}}\, dj \tag{3.37}$$

The total of workers supplying routine tasks for Home firms is $N_{f,t} = N_{r,t} + N_{OF,t}$ where $N_{OF,t}$ is the amount of foreign workers supplying routine labor for Home firms. We can express the shares of each type of workers over the number of workers producing routine tasks for Home firms as:

$$\frac{N_{OF,t}}{N_{f,t}} = G(J_{OF,t}), \qquad \frac{N_{r,t}}{N_{f,t}} = 1 - G(J_{OF,t}) \tag{3.38}$$

Finally, given the assumption of uniform distribution, we can easily define the location decision cutoff as:

$$J_{OF,t} = j_{max}\frac{N_{OF,t}}{N_{f,t}} \tag{3.39}$$

3.3.4 Non-tradable sector

Production in the non-tradable sector is supplied by perfectly competitive firms that only use manual labor as input. Low-skill workers supply manual tasks with the same productivity. As such, the non-tradable production function is defined as:

$$Y_{N,t} = N_{m,t}x_{m,t} \tag{3.40}$$

with $x_{m,t}$ normalized to 1 as explained before. In each firm, workers earn the basic gross real wage $w_{m,t} = W_{m,t}/P_{T,t}$. As such, the price of the non-tradable good in terms of the price of the tradable good equals the wage divided by the productivity differential:

$$\frac{P_{N,t}}{P_{T,t}} = \frac{w_{m,t}}{x_{m,t}} \tag{3.41}$$

3.3.5 Equilibrium

As the government cannot issue debt, at each period, taxes on labor and capital incomes must be equal to government spending:

$$G_t = \tau_w(W_{m,t}N_{m,t} + W_{r,t}N_{r,t} + W_{a,t}N_{a,t}) + \tau_k(R_{k,t} - \delta_k/\epsilon_{K_t})K_t \tag{3.42}$$

Aggregate production is simply the sum of productions of tradable and non-tradable goods:

$$Y_t = Y_{T,t} + Y_{N,t} \tag{3.43}$$

The demand for non-tradable goods is divided between consumption, investment and government spending. As such, we obtain for the Home country the following equation for the demand of non-tradable goods:

$$Y_{N,t} = (1-\alpha_y)\left(\frac{P_{N,t}}{P_t}\right)^{-\rho}(C_t + I_t + G_t) \tag{3.44}$$

Tradable goods can also be used for the training and offshoring costs. As such, we obtain the following demand equation:

$$Y_{T,t} = \frac{f_{Na,t}}{P_t}N_{Na,t} + \frac{f_{Nr,t}}{P_t}N_{Nr,t} + \frac{\Upsilon_t}{P_t} + y_{H,t} + y_{F,t} + \alpha_y\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}G_t \tag{3.45}$$

with $\Upsilon_t = \left(\int_1^{J_{OF,t}} F(j) - 1\right)w^F_{r,t}T_t N_{OF,t}\, dj$ the supplementary offshoring cost and $y_{H,t}$ and $y_{F,t}$ the consumption and investment demands for the Home tradable good in the Home and the Foreign countries respectively. As I make the assumption of a small open economy, I take the limit for the size of the Home country $n \to 0$. This means that the different demands for tradable goods are defined as:

$$y_{H,t} = \alpha_y\left(\frac{P_{H,t}}{P_t}\right)^{-\rho}(1-\mu)\left(\frac{P_{T,t}}{P_{H,t}}\right)^{-\phi}(C_t + I_t) \tag{3.46}$$

$$y_{F,t} = \alpha^F_y\left(\frac{P^F_{H,t}}{P^F_t}\right)^{-\rho}\mu\left(\frac{P_{T,t}}{e_t P^F_{H,t}}\right)^{-\phi}(C^F_t + I^F_t) \tag{3.47}$$

where the Foreign variables are exogenous. Foreign exchanges imply the following equality:

$$N_{OF,t}w^F_{r,t}T_t\frac{P_{T,t}}{P_t} + S_t y^F_{H,t} = y_{F,t} \tag{3.48}$$

with S_t the real terms of exchange: $S_t = P^F_t/P_t$ and $y^F_{H,t}$ the demand of Foreign goods in the Home country.

3.4 Parameter values

General Strategy. The small open economy is built to resemble Spain as it is an important country of the European Union which has faced a large labor-market polarization and a considerable decrease of ICT-capital prices over the last two decades. The parametrization follows the values used in Maillard (2021) for parameters that should be similar for all countries of Western Europe. Otherwise, I follow the same parametrization strategy but use the values that allow to match key characteristics of Spain in 2016. Values in the Rest of the World are exogenous. They are set to be equal to their steady-state counterpart in the small open economy (in per-capita terms). As I am focusing on structural changes and not business cycle issues, a period corresponds to a year. Hence, β is calibrated to 0.96.

Employment and labor productivity. To match the estimation of the Frisch elasticity found in Chetty (2012), I must have $\zeta = 1/0.75$. I choose $\bar{N}_t = 0.5$ as usual in the literature without loss of generality. Matching this value requires $\chi = 4.24$. The relative amount of each type of labor is set using the data from the European Center for the Development of Vocational Training (CEDEFOP) for 2016.[5] This gives the following shares: $\bar{N}_a/\bar{N} = 34.32\%$, $\bar{N}_r/\bar{N} = 28.73\%$ and $\bar{N}_m/\bar{N} = 36.95\%$. I obtain occupational earnings data from the International Labour Organization database (ILOSTAT). I get the following productivity differentials between sectors: $x_r = 1.4$ and $x_a = 2.3$. Furthermore, the annual job separation rate is $\delta_a = \delta_r = 0.115$, which corresponds to a 3% quarterly separation rate. This parametrization implies an abstract training cost of $f_{Na} = 10.55$ and a routine training cost of $f_{Nr} = 3.24$.

Production. The depreciation rate of capital is $\delta_k = 0.20$ as estimated by Eden and Gaggl (2018) for the United States. Moreover, α_k is calibrated so that ICT-capital income is equal to 8% of total income.[6] As such, $\alpha_k = 0.230$. Furthermore, to match the shares

[5] See Maillard (2021) for a precise definition of the three different categories.
[6] This follows the estimation in Eden and Gaggl (2018) when removing non-ICT capital.

of routine labor, abstract labor and ICT capital with the data, I must impose $\alpha_r = 0.358$. The elasticity of substitution between tradable and non-tradable goods ρ is set to 0.44, the elasticity of substitution between ICT capital and abstract labor σ to 0.67 and the elasticity between abstract and routine labor θ to 1.67 as in Krusell et al. (2000) and Mandelman and Zlate (2021).

Offshoring, trade and openness. For this chapter, I only look at offshoring done for cost reasons with a sub-part of the Rest of the World: Central and Eastern Europe and the developing countries of Asia that trade the most with European countries (China, India and Indonesia). Using ILOSTAT, I choose a wage in the offshoring region that is a third of the Spanish steady-state routine wage: $w^R_{r,t} = \bar{w}_r/3$. Then, I consider that the share of offshored routine tasks is equal to the share of goods imported by Spain from those regions that are produced by the manufacturing sector for the manufacturing sector. I obtain this data in the World Input-Output Tables (WIOT).[7] However, WIOT are only available until 2014. As such, I match the offshoring dynamics from 2000 to 2014 with my model and use the value I find for 2016. I obtain $G(J_{OR}) = 6.9\%$. To get the value of the trade cost, I use the ESCAP-World Bank (2021) bilateral-iceberg trade cost database based on Novy (2013). I weight those costs by trade quantities using the WIOT. I obtain the trade cost value $\tau = 1.89$. Besides, given the target quantity of offshoring, the level of trade costs and the wage differentials between countries, the cost parameter for offshoring is $z = 5$. As usual in the international macroeconomic literature, I choose a value of $\phi = 1.5$ for the trade elasticity. I also normalize the terms of trade $\bar{T} = 1$ in the steady-state. The size of the openness of Spain is set to match the ratio of import to final-good demand using the WIOT.[8] The ratio obtained is close to 8%. To match it, I need $\mu = 0.14$. Finally, consistency between the chosen parameter values and the structural equations of the model

[7]See Timmer et al. (2015) for details on those tables.

[8]I only take into account imports from other European countries and the three main Asian countries. Besides, I remove the goods that are produced by and sold to the manufacturing sector from the calculation, as I considered them as offshoring and not final goods.

constrains the size of the tradable-good sector and requires $\alpha_y = 0.739$.

Government policies. As a baseline, I decide to choose $G_t = 0$ to better understand the mechanisms of the model. As such, $\tau_k = \tau_w = 0$. The values of the parametrization are summarized in Table 3.1 below.

Table 3.1: Parametrization for the baseline model

	Symbol	**Value**
Discount factor	β	0.96
Steady-state share of abstract labor	$\bar{N}_a/\bar{N}$	0.343
Steady-state share of routine labor	$\bar{N}_r/\bar{N}$	0.287
Steady-state share of manual labor	$\bar{N}_m/\bar{N}$	0.370
Frisch elasticity	$1/\zeta$	0.75
Depreciation rate of ICT capital	δ_K	0.20
Job separation rates	$\delta_a = \delta_r$	0.115
Cost of abstract training	f_{Na}	10.55
Cost of routine training	f_{Nr}	3.24
Trade elasticity	ϕ	1.5
Elasticity of substitution tradable and non-tradable goods	ρ	0.44
Elasticity of substitution ICT capital and abstract labor	σ	0.67
Elasticity of substitution routine and abstract labor	θ	1.67
Steady-state routine productivity	x_r	1.4
Steady-state abstract productivity	x_a	2.3
Share of ICT capital	α_k	0.230
Share of routine labor	α_r	0.358
Share of the tradable sector	α_y	0.739
Openness	μ	0.14
Share of routine production offshored	$\bar{G}(J_{CR})$	0.069
Trade cost	τ	1.89
Offshoring wage	$w_{OR,t}$	$\bar{w}_{r,t}/3$
Offshoring cost parameter	z	5

3.5 Results

The objective of this section is to study in details the consequences of implementing a taxation/subsidy on robots. First, I compute the Ramsey-optimal tax plan and examine its consequences in terms of welfare and of the main variables. Second, I analyze the consequences of a more moderate subsidy. Third, I look at the role of adding this subsidy in a dynamic setting where ICT-capital prices decrease at each period.

3.5.1 Ramsey policy

First, I intent to find the value of ICT-capital taxation/subsidy that maximizes the welfare of the large family of the small open economy. To do so, I compute the Ramsey-optimal plan that solves the usual competitive equilibrium problem using only robot taxation/subsidy τ_K as instrument. I consider that the social welfare function is:

$$Welf = \sum_{t=0}^{\infty} \beta^t u(C_t, 1 - N_t) \tag{3.49}$$

I solve the problem in Dynare (see Adjemian et al. (2011)), with the help of the program from Levin et al. (2005) to obtain the numerical steady-states of the Lagrange multipliers. I show the steady-state tax-rate levels as well as the changes in terms of welfare and of the main variables between the steady-state of the status-quo economy and the steady-state of the Ramsey-optimal plan for the model with the baseline specification but also other model specifications in Table 3.2.

Results for the baseline specification model are depicted in column (I). As we can see, the optimal level of robot taxation is a subsidy of 6,312 (or 631,200%). This result has two main reasons: the low size of the ICT-capital stock and the fact that capital and labor incomes are equally distributed among members of the large family. As such, it is optimal to have an almost null net return on ICT capital ($R_{k,t} - \delta_k/\epsilon_{K,t}$) and to pay the low level of taxation on labor (2.4%) that compensates this subsidy. The subsidy leads to a drop of the price of ICT capital which causes an increase of investment in robots. Due to the relative complementarity of ICT capital with abstract labor and their relative substitutability with routine labor, this increase of automation causes a decrease of the share of routine workers and an increase of the shares of both abstract and manual workers. However, as the size of the ICT-capital stock is low, changes in the distribution of employment are very small. Besides, as the price of ICT capital is lower for the firm, the price of the tradable good decreases, leading to a rise of its demand at Home and in the Rest of the World, increasing total output. To face this new demand, productivity of labor endogenously increases. The complementarity between abstract tasks and ICT capital means that abstract productivity increases more than routine productivity. Nevertheless, both types of wages rise. Manual wage also slightly increases as tradable and non-tradable goods are complement and the presence of a positive labor tax slightly diminishes labor supply. Finally, despite the decrease in total labor supply, the increase of wages and the decrease of the price of the domestic tradable good causes a small increase in consumption. Thus, as consumption rises and the disutility from labor decreases, it logically brings an increase of welfare.

In the following columns of Table 3.2, I study other specifications of the model to see whether this result of a very large optimal subsidy of ICT capital is consistent across models. Column (II) indicates the results when the supply of total labor is inelastic: $N_t = \bar{N} = 0.5$. As such, there is no disutility from labor and modifying the tax level on labor has no effect on N_t. In this case, the optimal level of robot subsidy becomes 19,787. Although it is higher than in the baseline, it remains of the same order of magnitude. The consequences for the main variables are comparable with column (I). The main difference is that consumption increases more as labor supply remains identical. At the end, the size of the welfare increase is very similar to the baseline case as the decrease in labor disutility does not occur in this case.

Table 3.2: Consequences of the Ramsey policy for the main variables

	I	II	III	IV	V	VI
τ_K	-6,312	-19,787	-18,503	-2,976	-2,663	-8,091
τ_w	0.0240	0.0240	0.2356	0.0240	0.0247	0.0240
$Welf$	0.148	0.165	0.065	0.147	0.095	0.149
N	-0.55	0	-0.65	-0.55	-0.54	-0.55
N_a/N	0.66	0.65	0.49	0.66	0.57	0.65
N_r/N	-3.01	-2.97	-2.95	-3.01	-3.07	-3.01
N_m/N	1.73	1.71	1.84	1.73	1.85	1.74
w_a	4.23	4.22	4.49	4.23	4.21	4.26
w_r	3.52	3.52	3.62	3.52	3.41	3.54
w_m	2.80	2.79	2.74	2.80	2.87	2.80
C	0.13	0.66	-0.28	0.13	0.02	0.14
Y	1.99	2.53	2.01	1.99	1.89	2.01
T	1.07	1.34	1.16	1.07	1.1	1.07

Tax rates are in absolute values. Welfare results are shown as a linear difference between the optimal-Ramsey and the status-quo models as consumption is included in the utility function as $ln(C_t)$. The other variables are presented as a difference expressed in percentage between the optimal Ramsey and the status-quo models. The different model specifications, precised in the main text, are the following: (I) baseline, (II) no labor margin, (III) government spending (IV) complete financial markets, (V) mobility costs and (VI) possible unemployment.

The model specification in column (III) adds positive government spending to the baseline model. Following World Bank data for Spain, I choose $G_t = 0.19Y_t$. As such, labor taxes become positive in the status-quo economy: $\tau_w = 0.2126\%$. Computing the Ramsey optimal plan, I obtain a subsidy on robots of 18,503. Here, the weight on labor imposed by the original taxation level means that the increase in labor taxation leads to a slightly higher decrease in labor supply. As such, despite the decrease of the price of the tradable good, consumption diminishes. Nevertheless, the diminution of the disutility of labor means that welfare increases. But, the rise of welfare is almost 60% lower than in the baseline model specification.

In column (IV) I look at the results when I add perfect financial markets to the baseline model. In this case, as I assume symmetric initial conditions across countries, perfect insurance between countries implies:

$$U_C(C_t^F) = U_C(C_t)S_t \tag{3.50}$$

which gives:

$$C_t^F S_t = C_t \tag{3.51}$$

As we can see, with this model specification, the Ramsey plan has almost identical consequences for the main variables as the baseline model specification. Although the robot subsidy is somewhat lower, the main variables vary similarly and the welfare gains are the same. Therefore, the presence of this insurance mechanism between the small open economy and the Rest of the World seems rather irrelevant for the Ramsey plan.

In the last two columns, I use model specifications that include different costs to labor-market polarization. First, in column (V), I add mobility costs to the baseline model specification. Becoming an abstract or a routine worker implies a cost supplementary to the training cost. It is included in the utility function as follows:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t) - \chi \frac{N_t^{1+\zeta}}{1+\zeta} - \gamma_{a,t} N_{Na,t} - \gamma_{r,t} N_{Nr,t} \right] \tag{3.52}$$

where $\gamma_{i,t} = \gamma_i W_{m,t}$ with $i \in \{a, r\}$ are the mobility costs. This modifies the equations defining the cost to become abstract and routine workers (2.10) and (2.11):

$$f_{Na,t} = \pi_t + (1-\beta(1-\delta_a))\gamma_a P_t C_t + \beta E_t \left\{ (1-\delta_a) \frac{P_t C_t}{P_{t+1} C_{t+1}} f_{Na,t+1} \right\} \tag{3.53}$$

$$f_{Nr,t} = \eta_t + (1-\beta(1-\delta_r))\gamma_r P_t C_t + \beta E_t \left\{ (1-\delta_r) \frac{P_t C_t}{P_{t+1} C_{t+1}} f_{Nr,t+1} \right\} \tag{3.54}$$

I choose $\gamma_a = \gamma_r = 2.61$ following the estimation of mobility costs in Western Europe provided in Artuc, Lederman, and Porto (2015).[9] As we can see in column (V), with mobility costs, the optimal robot subsidy becomes 2,663. The welfare increase is 36% lower than in the baseline model. Indeed, less workers become abstract or routine workers than in column (I) as the cost of up-skilling increases. As such, there are more manual workers and the average wage is lower. Therefore, consumption is very close to its value in the steady-state of the status-quo economy. Nevertheless, the diminution in the disutility of labor causes an increase in welfare.

Finally, in column (VI), I allow for the possibility of unemployment for individuals that are separated from a routine work. This is indeed a fear of many opponents to automation. Unemployment is included in the following way:

$$U_t = U_{t-1} + 0.5 \times (N_{Nr,t-1} - N_{Nr,t}) \tag{3.55}$$

This means that half of the routine workers that are not replaced become unemployed and cannot find a job. In this case, the optimal robot subsidy becomes 8,091. Unemployment is barely superior to 0.5% of the labor force in the steady-state of the Ramsey economy as the decrease of routine employment is low. As such, members of the large family that work compensate this new unemployment by deciding not to decrease their own labor supply contrarily to what occurs in the previous model specifications. Therefore, the final consequences on labor supply and welfare changes are very similar to those of the Ramsey plan obtained for the baseline model specification.

Thus, despite some differences in magnitude, the Ramsey optimal plan calls for an extremely high robot subsidy for all model specifications.[10] Even adding labor-polarization costs as in column (V) and (VI), does not modify this result. In all cases, the subsidy is compensated

[9] In this specification, I must also make some small modifications to the size of each factor in the production functions to maintain the same size of capital income with respect to total income.

[10] I conduct other robustness checks in the Appendix to check the role of the value of the different elasticities of substitution and of the presence of offshoring or final trade. They do not modify the main result of the optimality of a very high robot subsidy.

by a labor tax of around 2.4pp. Wages increase due to a rise of productivity while abstract and manual employment shares slightly increase and the routine labor share decreases.

3.5.2 Example with a realistic subsidy

As the subsidy found by solving the Ramsey plan is highly unrealistic, in this subsection, I look at the consequences of a more realistic subsidy of 50% for the same model specifications as before. I show the steady-state tax-rate levels as well as the differences of welfare and of the main variables between the steady-state of the status-quo economy and the steady-state of the economy with the robot subsidy in Table 3.3 below.

The main variables move similarly than for the Ramsey plan but at a much lower magnitude. The results for the baseline model specification are shown in column (I). A 50% robot subsidy brings an increase of welfare that is 64% lower than the optimal Ramsey plan. The subsidy is compensated by a tax on labor of 0.69%. Similarly, the subsidy leads to a decrease of the return of ICT capital. Therefore, the cost of automation diminishes for firms and they decide to increase their amount of ICT capital. As such, the share of routine workers diminishes while the shares of abstract and manual workers increase. Again, the price of the tradable good decreases, leading to an increase of its demand. The productivity of workers rises to respond to this new demand, leading to an increase of wages. This increase of wages allows for an increase of output, consumption and welfare.

Results in Column (II), (III) and (IV) are very similar to results in the baseline model specification. In column (II), when there is no labor margin, the welfare increase is slightly higher than for the baseline model specification. Indeed, there is no decrease of the labor supply so consumption and output increase more than for the baseline study. In column (III), the labor supply decreases more because of the original taxation level. As such consumption slightly decreases as for the Ramsey-optimal plan and welfare gains are 43% lower than in the baseline model specification. For the model specification with complete

Table 3.3: Consequences of having a 50% robot subsidy for the main variables

	I	II	III	IV	V	VI
τ_K	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
τ_w	0.0069	0.0069	0.2192	0.0069	0.0071	0.0069
$Welf$	0.053	0.058	0.030	0.050	0.036	0.054
N	-0.16	0	-0.19	-0.16	-0.15	-0.16
N_a/N	0.23	0.22	0.18	0.23	0.21	0.23
N_r/N	-0.92	-0.91	-0.91	-0.91	-0.93	-0.92
N_m/N	0.51	0.50	0.54	0.50	0.53	0.51
w_a	1.25	1.24	1.32	1.25	1.23	1.25
w_r	1.05	1.05	1.08	1.05	1.01	1.05
w_m	0.85	0.85	0.83	0.85	0.87	0.85
C	0.08	0.23	-0.04	0.07	0.04	0.08
Y	0.60	0.76	0.61	0.61	0.57	0.61
T	0.32	0.40	0.35	0.36	0.33	0.32

Tax rates are in absolute values. Welfare results are shown as a linear difference between having a subsidy of 50% on robots and the status-quo as consumption is included in the utility function as $ln(C_t)$. The other variables are presented as a difference expressed in percentage between having a subsidy of 50% on robots and the status-quo. The different model specifications, precised in the main text, are the following: (I) baseline, (II) no labor margin, (III) government spending (IV) complete financial markets, (V) mobility costs and (VI) possible unemployment.

financial markets (column (IV)), the results are basically identical to the baseline model specification.

As we can see in column (V), adding mobility cost leads to a lower increase of the share of abstract worker and a higher decrease of the share of routine workers as the cost to switch occupation increases. As such, welfare changes are 32% lower than for the baseline model specification. Finally, with forced unemployment – column (VI) – workers compensate by diminishing less their own labor supply. As such, results are very similar to those in the baseline model specification.

Thus, whatever the model specification studied, implementing a 50% subsidy on ICT capital has a small but positive effect on aggregate welfare for the small open economy. Those results are consistent with recent papers as the one of Humlum (2019) but also with the aggregate benefits of automation found in Koch, Manuylov, and Smolka (2021) for Spain and Aghion et al. (2020) for France.

3.5.3 Transition with a yearly ICT-capital price decrease

Spain has seen ICT-capital prices strongly decrease at least since 2000. Indeed, as shown in Figure 3.4 in Appendix 3.7.1, it has decreased by more than 60% between 2000 and 2016. As such, it is crucial to consider this price decrease when studying the consequences of implementing a robot subsidy in a dynamic setting. In this subsection, I examine the possible dynamics of welfare and of the main variables between 2016 and 2030 with ICT-capital price decrease and with or without a robot subsidy. Considering previous trends, I make the ICT-capital price decrease by 5% each year. This means that it drops by slightly more than 50% between 2016 and 2030. The dynamics in this model, without robot subsidy, are only due to this drop in price. For the model with robot subsidy, on top of the ICT-capital price drop, a 50% robot subsidy is implemented according to the following process:

$$\iota_t = (1-\rho_\iota)Z_t + \rho_\iota \iota_{t-1} \tag{3.56}$$

$$\tau_{K,t} = 0^{\iota_t} \times \left(-0.5^{(1-\iota_t)}\right) \tag{3.57}$$

At the end of period 0, Z_t switches from 1 to 0, which triggers the convergence process. The speed of the convergence is governed by ρ_ι, the persistence of ι_t. I use $\rho_\iota = 0.7$ which means that the subsidy reaches 70% of its final value by 2020 and more than 99% of its final value in 2030.

To determine the welfare consequences of implementing a robot subsidy in the presence of the ICT-capital price decrease, I calculate the Hicksian-equivalent consumption change implied by the simulation over the 15 years. The Hicksian-equivalent change measures during T periods the percentage of permanent per-capita consumption ξ that the large family would have to lose – or gain – to be indifferent between the situation without any change and the situation where ICT-capital prices decrease and a robot subsidy is implemented :

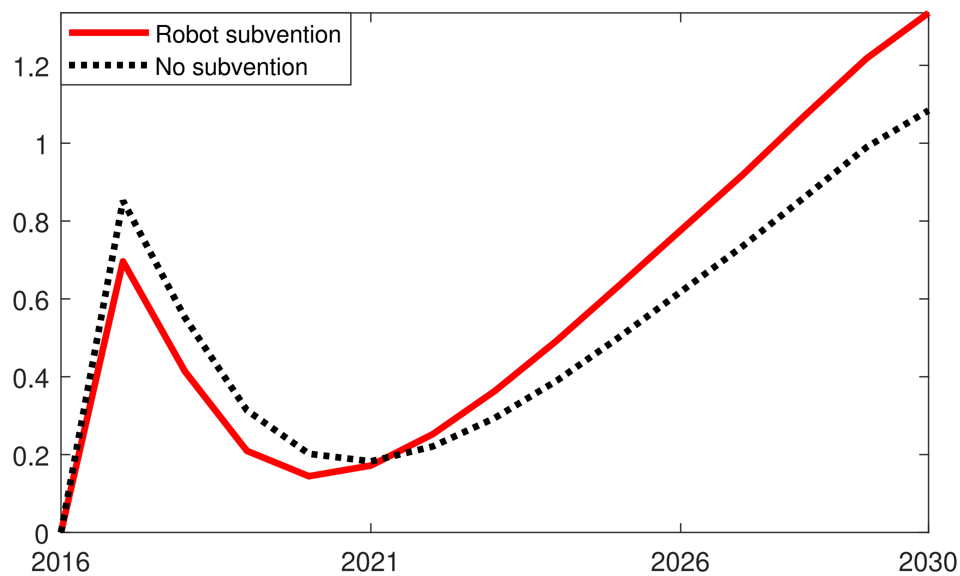
$$E_{2016} \sum_{t=2016}^{2030} \beta^t \Big[u\big((1-\xi)C_t, 1-N_t\big) \Big] = \sum_{t=2016}^{2030} \beta^t \Big[u(C_{2016}, 1-N_{2016}) \Big] \tag{3.58}$$

As such, it is a measure of aggregate cumulative welfare gains or losses for the small open economy. The model is solved using perfect-foresight non-linear simulations in Dynare. I present the welfare impact of only taking into account ICT-capital price decrease; and of also adding a robot subsidy in Figure 3.1.[11] The dynamics of the distribution of employment is displayed in Figure 3.2 and the dynamics of the other main variables in Figure 3.3.

As we can see, the decrease of ICT-capital prices leads to an increase of welfare. A yearly 5% decrease of this price would lead to a rise of aggregate welfare of around 1.1% of permanent consumption from 2016 to 2030. Although cumulative welfare change is always positive during the period studied, welfare gains decrease between 2017 and 2021. At the beginning of period 1, the shock is unexpected and the equilibrium conditions are not necessarily respected. The family decides to diminish investment to increase consumption and the number of workers training to become abstract workers. However, this has negative consequences on the following period. Indeed, the previous drop of investment leads to a fall of capital stock. First, this means that capital gains decrease. Second, due to the complementarity between abstract labor and ICT capital, the number of abstract workers diminishes. This causes a drop of the average wage. As such, both capital and labor gains decrease, leading to a diminution of consumption and utility in 2018. Only from 2021 onwards, the increase of investment due to the decrease of ICT-capital price materializes.

[11] The welfare dynamics for the five other model specifications are shown in Appendix 3.7.2

Figure 3.1: Welfare gains

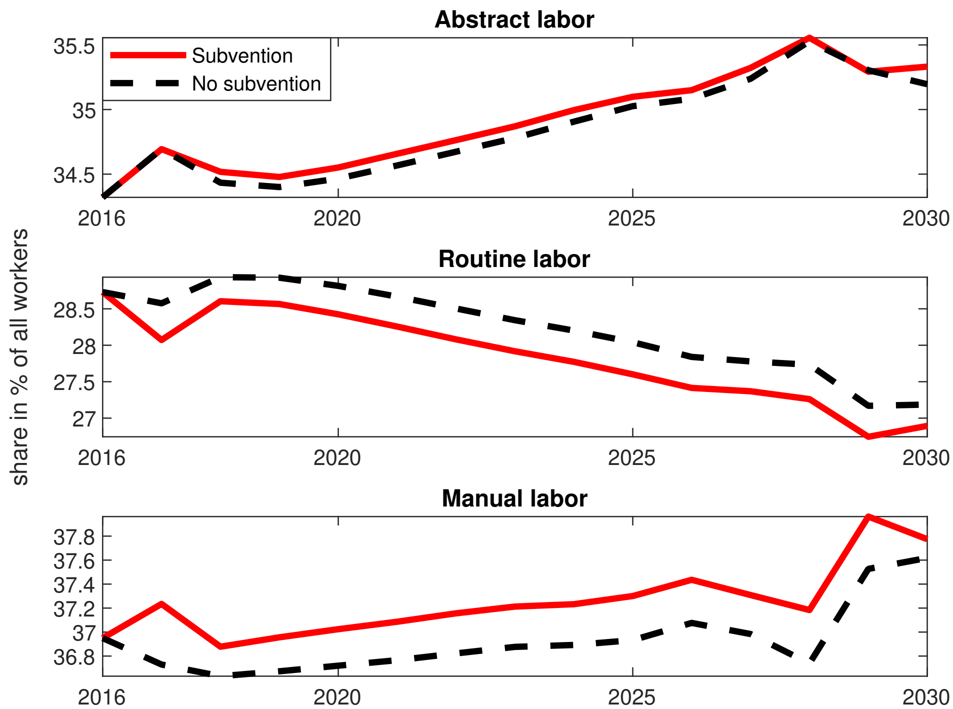


Results are expressed in percentage of permanent per-capita consumption of the baseline model specification.

This causes the increase of productivity, wage and of abstract employment required to increase output, consumption and welfare. This rise continues until the end of the period studied.

Adding a 50% robot subsidy brings higher welfare gains over the period with gains of 1.35% of permanent consumption in 2030. The gains follow a similar dynamic than without the subsidy. However, gains are lower in the short run and become higher only from 2021. The short-run differences come from the fact that the robot subsidy causes a stronger decrease of routine labor in period 1 and, therefore, the manual labor share does not decrease in the short-term as in the previous case. As such, average wage is slightly lower in the short term. Nevertheless, as the cost of automation is lower with the subsidy, productivity and wages increase more than without it. From 2021, this wage increase compensates the fact that the

Figure 3.2: Dynamics of the distribution of employment

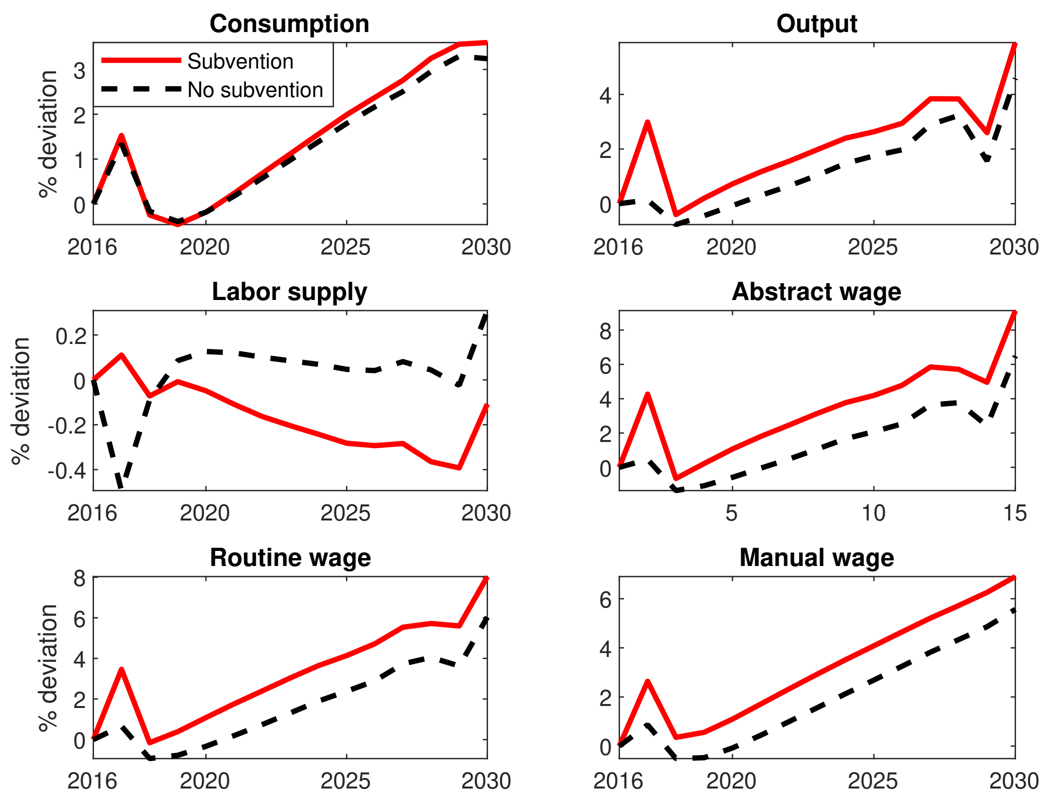


subsidy leads to a higher decrease of routine labor. Finally, while the robot subsidy brings higher welfare gains over the period studied, those gains are quite low compared with the gains coming from the decrease of ICT-capital prices. Gains increase by about 25% with the implementation of the subsidy.

3.6 Conclusion

In this chapter, I study the welfare consequences of implementing a robot subsidy in a small open economy resembling Spain. I build a general equilibrium model where routine workers can be replaced by robots or by offshored workers. First, I compute the optimal Ramsey model when robots can be taxed or subsidized. I find that it is welfare maximizing to

Figure 3.3: Dynamics of other main variables



implement an extremely high robot subsidy as the size of ICT-capital income is very small compared with labor income. Second, I look at the consequences of setting a more realistic robot subsidy of 50%. In this case, welfare gains are about a third as high as with the optimal subsidy. Third, I take into account the ICT-capital price decrease to understand the role of robot subsidy in a dynamic setting. I find that the drop of ICT-capital price increases welfare at any point during the fifteen-year period studied with or without the robot subsidy. Implementing the robot subsidy causes slightly lower gains in the short run as routine labor decreases more but higher gains after a few periods as wages are higher.

This chapter brings to the literature a detailed study of the consequences of robot taxation/subsidy on aggregate welfare and other main economic variables for a small open economy resembling a European country. However, it is important to keep in mind that this chapter does not take into account the redistributive consequences of robot taxation/subsidy. These considerations are left for future research.

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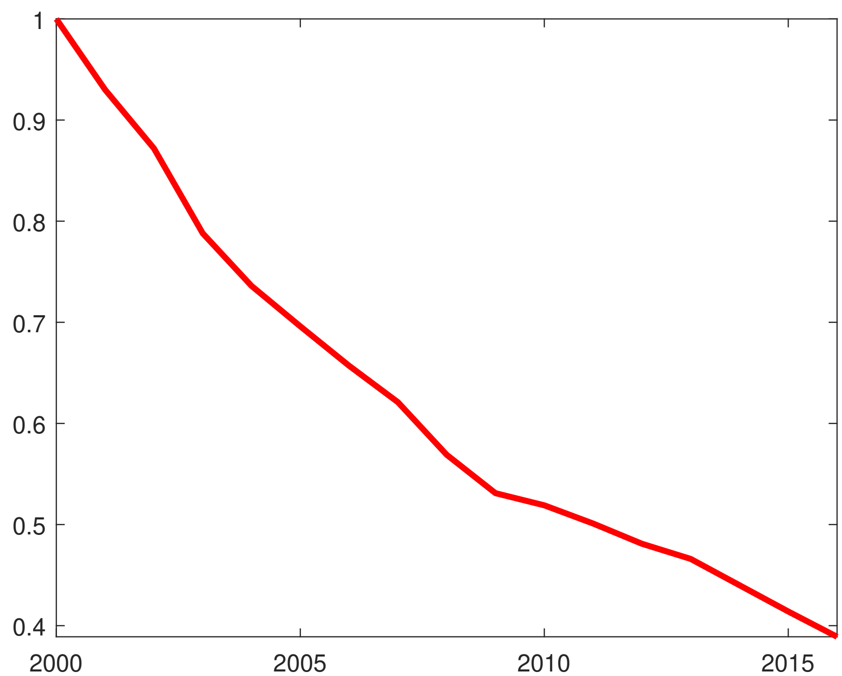
3.7 Appendix

3.7.1 Data

Figure 3.4: ICT-capital price dynamics (normalized to 1 in 2000)



Data comes from the EU KLEMS database. ICT capital includes computing equipment, communication equipment, and computer software and databases.

3.7.2 Robustness checks

Ramsey policy

I conduct several robustness checks of the Ramsey-optimal policy to see the role played by the values of the different elasticities of substitution and of the presence of offshoring or trade. I show the steady-state tax-rate levels as well as the difference of welfare and main variables between the steady-state of the status-quo economy and the Ramsey-optimal plan in Table 3.4. The baseline results are reproduced in column (I) and the robustness checks on the other columns.

Table 3.4: Consequences of the Ramsey policy for the main variables

	I	**Ib**	**Ic**	**Id**	**Ie**	**If**	**Ig**
τ_K	-6,312	-2,892	-3,209	-3,166	-3,315	-3,321	-3,497
τ_w	0.0239	0.0238	0.232	0.0244	0.0235	0.0238	0.0233
$Welf$	0.148	0.234	0.159	0.168	0.141	0.126	0.131
N	-0.55	-0.72	-0.50	-0.62	-0.51	-0.45	-0.44
N_a/N	0.66	5.49	1.72	1.34	0.47	0.53	0.5
N_r/N	-3.01	-9.81	-3.34	-2.33	-2.71	-2.73	-2.68
N_m/N	1.73	2.53	1.00	0.57	1.67	1.63	1.63
w_a	4.23	4.15	4.21	4.28	4.15	4.16	4.14
w_r	3.52	3.45	3.53	3.56	3.46	3.46	3.45
w_m	2.80	2.73	2.83	2.83	2.75	2.75	2.75
C	0.13	0.33	0.22	0.16	0.13	0.13	0.16
Y	1.99	2.87	1.71	2.30	1.83	1.90	1.91
T	1.07	1.09	0.74	1.39	0.81	3.27	1.60

Tax rates are in absolute values. Welfare results are shown as a linear difference between the optimal-Ramsey and the status-quo models as consumption is included in the utility function as $ln(C_t)$. The other variables are presented as a difference expressed in percentage between the optimal Ramsey and the status-quo models. The different model specifications, precised in the main text, are the following: (I) baseline, (Ib) $\theta = 5$, (Ic) $\sigma = 0.35$ (Id) $\rho = 1.1$, (Ie) No offshoring (If) No final trade and (Ig) No final trade or offshoring.

In column (Ib), I look at the results when I choose a higher elasticity of substitution between routine and abstract workers $\theta = 5$.[12] In this case, the optimal robot subsidy is 2,892. Choosing $\theta = 5$ means that the subsidy leads to a much higher decrease in routine labor and a bigger increase in abstract labor. The rise in abstract employment increases the average wage leading to welfare gains 58% higher than in the baseline. Nevertheless, the optimal subsidy level remains of a similar magnitude.

[12] This is the value that is needed to explain the complete polarization of labor markets in Europe as shown in Maillard (2021).

Column (Ic) shows the results when I choose a low elasticity of substitution between ICT capital and abstract workers $\sigma = 0.35$. In this model specification the Ramsey plan finds a subsidy of robot taxation of 3,209. It brings a higher polarization of employment than for the baseline model specification as the complementarity between abstract labor and robots is higher. It causes a welfare change that is 7% higher than for the baseline model specification.

I also look at the differences with a high value of the elasticity of substitution between the tradable and the non-tradable goods $\rho = 1.1$ in column (Id). In this case I obtain a robot subsidy of 3,166 for the Ramsey-optimal plan. As ρ is superior to 1, the benefits of an increase of the demand for the tradable good do not spread to the non-tradable good. As such, the increase of the number of manual workers is lower than for the baseline specification while the one of the number of abstract workers is higher. That leads to a welfare increase 14% higher than in the baseline model specification.

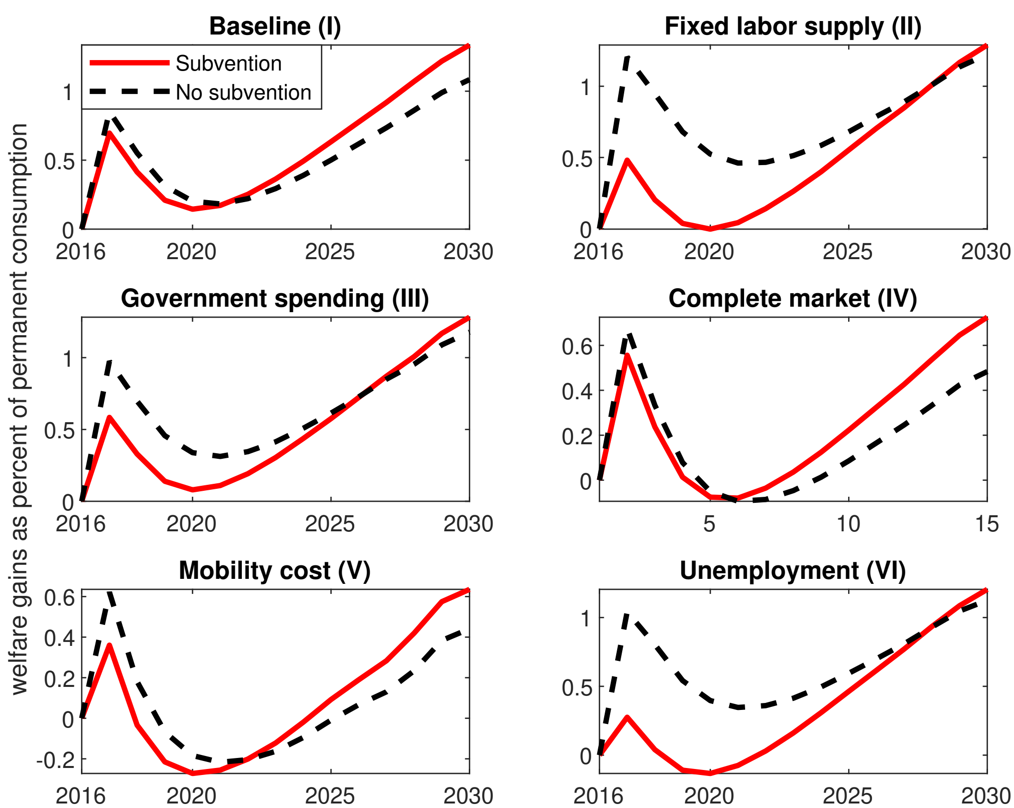
Finally, the last three columns (Ie), (If) and (Ig) give respectively the results of the Ramsey plan when there is no offshoring allowed, no final trade allowed and neither offshoring nor final trade allowed. They indicate that offshoring and final trade only play a small role in explaining steady-state values in the Ramsey-optimal plan. In all three cases, the welfare gains are slightly lower than in the baseline. Indeed, removing final trade limits the increase of the demand for the domestic tradable good as there is no foreign demand while removing offshoring limits the choice of the input for the routine task. As such, in all three cases, the movements caused by the subsidy diminish: labor polarization, the wage increase and the labor supply decrease are all lower.

Thus, the need of a very strong robot subsidy to maximize welfare seems very robust to different model specifications.

Transition with ICT-capital price decrease

I perform the same transition welfare exercise as in the main text with the other model specifications as a robustness check. Results for the baseline model and the five other model specifications are shown in Figure 3.5. All models follow the same dynamics: with or without the robot subsidy, the economy experiences welfare gains; the cumulative gains in 2030 are higher with the subsidy and cumulative welfare gains decrease after 2017 for a few periods. However, there are some differences concerning the size of the welfare gains. The lowest gains occur with the presence of mobility costs. Cumulative gains are almost 50% lower than for the baseline model specification in 2030. Besides, in this case, the country experiences welfare losses for a few periods during the transition process. Small losses in the short run are also experienced for the model specifications (IV) and (VI) which are respectively models with complete financial markets and with unemployment. Finally, in the case of models (II), (III) and (VI), implementing the robot subsidy brings almost no additional cumulative welfare gain at the end of the period.

Figure 3.5: Welfare variations for the different models



Les Marchés du Travail Européens: Une Vision Macroéconomique

Résumé

Cette thèse organisée en trois chapitres s'intéresse aux modifications structurelles qui ont touché les marchés du travail européens ces dernières décennies. Le progrès technique a conduit à une automatisation des processus de production. Il a également causé une multiplication des échanges: le commerce de biens finaux et les délocalisations ont augmenté alors que les crises se sont mondialisées. Il est donc crucial de comprendre les conséquences de ces changements structurels ainsi que les moyens d'actions disponibles pour les pays européens pour y faire face. Le Chapitre 1 examine l'impact de la mise en place d'une homogénéisation des législations régissant les marchés du travail des pays de la zone Euro. Je trouve que si cette réforme est bien implémentée, elle peut amener à de larges gains de bien-être pour les pays avec les marchés du travail les plus rigides mais peut aussi augmenter le bien-être des pays plus flexibles. En plus, les gains sont présents dès que la réforme est mise en place. Le Chapitre 2 analyse les effets de l'automatisation et des délocalisations sur les dynamiques de la distribution de l'emploi entre 2000 et 2016. Je trouve que l'automatisation est le principal facteur expliquant la polarisation du marché de l'emploi. L'effet des délocalisations sur le remplacement des emplois routiniers par des emplois manuels non-routiniers et moins bien payés est aussi non négligeable. Malgré tout, les deux facteurs apportent des gains de bien-être, au moins après quelques années. Finalement, le Chapitre 3 étudie les conséquences de taxer ou subventionner les robots en Espagne. Je trouve que la politique maximisant le bien-être requiert une subvention extrêmement large. Une subvention plus réaliste apporte également des gains de bien-être, mais d'une magnitude plus faible que ceux provenant de la tendance actuelle de la baisse du prix des robots.

Mots clés: Marchés du travail européens, polarisation de l'emploi, Subvention aux robots, Homogénéisation des marchés du travail

European Labor Markets: A Macroeconomic Vision

Abstract

This PhD thesis, organized in three chapters, focuses on several labor-market structural changes that have occurred in Europe those last decades. Technical progress has led to the creation of machines and the automation of the production process. It has also caused a multiplication of international exchanges: trade of final goods and offshoring have increased while crises have become more global. It is therefore crucial to understand the consequences of those structural transformations and the means of action for European countries to face them. Chapter 1 examines the impact of implementing a homogenization of labor-market legislations in the Euro Area. I find that if properly implementing, such a reform could bring large welfare gains for the countries with the most rigid labor markets and it could even improve the welfare level of more flexible countries. Besides, gains appear as soon as the reform is implemented. Chapter 2 analyzes the effect of automation and offshoring on the dynamics of the distribution of employment in Western Europe from 2000 to 2016. I find that automation is the main factor explaining labor-market polarization. The effect of offshoring on the replacement of middle-skill labor by low-skill labor is also non negligible. Both factors bring welfare gains, at least after a few periods. Finally, chapter 3 conducts a study of the consequences of robot taxation/subsidy in Spain. I find that the welfare maximizing plan requires an extremely large subsidy. A more realistic subsidy still brings welfare gains but they are lower than the gains coming from the actual downward trend of robot price.

Keywords: European labor markets, employment polarization, robot subvention, labor-market homogenization