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The Role of ICT Imports on TFP Growth

A Sectorial Analysis on Ten OECD Countries

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The Role of ICT Imports on TFP Growth - A Sectorial Analysis on Ten OECD Countries

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Abstract

This bachelor thesis inspects the relations between the adoption information and communications technology (ICT) and the rate of growth of productivity. In particular, the aim of the study is to assess whether the imports of ICT has a positive impact on total factor productivity (TFP) growth. Indeed, ICT imports may affect the TFP through channels that differ from the domestic ICT like benefits from specialization and spillover effects. In order to test this hypothesis, an empirical analysis is conducted on thirteen industries of ten OECD countries during the period 2000 – 2007. The findings suggest that ICT imports do play a role for TFP growth and that there may be a substitution effect with the undertaking of R&D activity. Industries which invest little amount in R&D may increase their productivity by acquiring advanced ICT from abroad. At the same time, those industries that have a large R&D intensity may fail to gain additional boost in TFP from ICT imports.

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1. Introduction

During the last decades, the search for the deep determinants of economic growth has focused on one main thing: productivity. Its importance emerged thanks to the achievements in economic theory, which culminated with the design of the endogenous growth models. Since then, the interest of economists concentrated on this element, for whose complexity it has been named "the black box" of the production function. The predominant role of ICT has been supported from both theoretical and empirical point of views. On one side, the theory has demonstrated that, when you reduce economic growth models to their fundamental dynamics, the incentives mechanisms of every variable that enters the standard production function depends on productivity. At the same time, empirical evidence has corroborated its crucial contribution to economic growth. Therefore, the key role of productivity in causing and maintaining a sustainable growth is an established fact. Indeed, as the Nobel-prize winning economist Paul Krugman asserted "productivity is not everything, but in the long run it is almost everything".

Having illustrated the idea that productivity drives growth, now the issue is to define what productivity actually is. In fact, there are several ways to define it. Nevertheless, the gist is that productivity is what determines the difference between the value of the output and the value of the inputs used to produce it (Weil, 2010). The simple combination of human work and capital does not result in a mere sum of the twos; rather you finally obtain an outcome whose value outnumbers the inputs. Thus, productivity is the factor that takes place during the production process and that increases the final amount of the production. For this reason productivity can be considered as a parameter of efficiency. For instance, if firm A produces more output than firm B given the same inputs, the gap is due to differences in productivity. Maybe A's employees work more efficiently or maybe A's organisation reduces the time of production, in any case A is considered more efficient than B. From a farther standpoint, the same comparison can be undertaken across countries and industries by observing aggregate data.

However, the way that I have so far described productivity implies an undesired characteristic, since, conversely from labour and capital, it cannot be directly observed. Productivity is neither a tangible or intangible good nor a service, and it is not the result of a straightforward production process. Productivity is just there, it wax and wanes with patterns that have not been totally clarified yet. That is the reason why it is called the black box of the production function. Great share of the literature on economic growth from the '80s to nowadays deals with the study of the black box, trying to understand its sources, its dynamics and its effects. Our knowledge about it has extended largely so that we can compute productivity thanks to the Solow residual and we know that factors such as research and development activities (R&D), schooling and natural resources can influence it. Nevertheless, a clear and formal definition of productivity is not available yet (Lipsey and Carlaw 2001).

Nonetheless, two main kinds of productivities can be identified. On the one side, you have labour productivity, which can be simply measured as the ratio between the amount of output produced and the time that it took to produce it. On the other side, you have total factor productivity (TFP, also known as multifactor productivity), which is a parameter that captures the efficiency of all production factors. Clearly, the two measures have significant differences, so they deserve a brief explanation. Labour productivity is defined as the ratio between gross domestic product (or gross value added) and the total amount of hours dedicated to produce it. The result is a parameter that tells you how much output per hour it can be created. It has the main advantage to have a clear meaning, which can be easily linked to important concepts like standards of living. However, it is a poor parameter to define the overall efficiency of industries or countries. Conversely, total factor productivity is computed through growth accounting (see section 2.3.1.). This causes TFP to be a better measure to compute the efficiency of a country, but its calculation is more complicated. Nevertheless, the TFP is a better proxy for determining productivity, since it has several other advantages compared to the labour productivity. First, its measure takes into account the effectiveness of whole the factors of production, so that it better resembles a proxy for determining the overall efficiency of the production. Furthermore, it better represents a structural enhancement of the economic system. Indeed, if you imagine the technology level of a country as a sequence of rungs in which the lowest corresponds to the poorer state of technology, an increase ceteris paribus of the TFP means that the production activity has leaped to a higher rung of technological level. In this way, the new state of the economy consolidates and becomes part of the economic fabric of the country. Nevertheless, as pointed out by Sargent and Rodriguez (2001), there is not a unique kind of productivity which is optimal for every application, since it largely depends upon the research that you are doing. Following the school that deems TFP as a better proxy for efficiency, this study focuses on such element. Thus, for the rest of the thesis, TFP and productivity are used interchangeably.

Now, the question turns to understand the mechanisms that foster productivity. The research has identified several factors that contribute to this scope, but the technology related to information and communication is deemed to play a decisive role. Indeed, soon after the formulation by Solow of his famous paradox, a large number of studies concentrated on the analysis of the relation between information and communications technology (ICT) and productivity. A survey of the literature is presented in section 2.3., here I prefer to give some general facts about the importance of ICT.

Probably, the most evident issue that instantiates the importance of ICT for productivity growth is the existing gap between U.S. and Europe in (labour) productivity. After the II World War, Europe and U.S. experienced a constant improvement in productivity. However, as clearly illustrated by Van Ark, O'Mahony, and Timmer (2008), during the last decades the European productivity has failed to catch up with the American one. While American productivity has kept on raising, Europe has stagnated since the '80s. Figure 1 illustrates the problem, showing the value of GDP per hour worked for some European countries as percentage of the American labour productivity. The graph displays that the European labour productivity compared to U.S. in 2010 is 10% lower than the one in 1980. Many economists point to disparities in ICT adoption as one of the primary reasons for this gap. The massive investments in ICT by the U.S. has ensured a constant raise in productivity, whereas the delay of Europe has sentenced it to a stop in productivity growth. The lack of ICT capital has slowed the entering of the old continent into the so-called knowledge society.

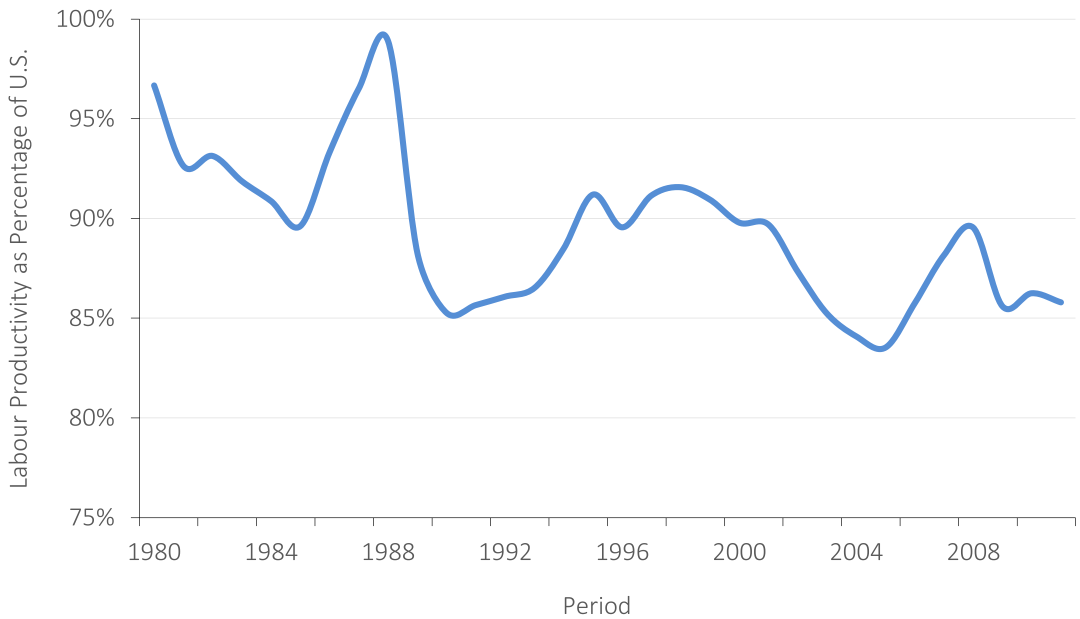

Figure 1. Productivity gap between Europe and United States. Labour productivity for the analysed countries as percentage of the American one, during the period 1980-2011. Specifically, the countries are those analysed by this thesis, that is: Austria, Czech Republic, Denmark, Finland, Germany, Italy, Netherlands, Slovenia, and Sweden. Source: Feenstra, Inklaar, and Timmer (2015).

Nevertheless, Europe is not looking passively to this gap; the importance of ICT in order to sustain growth is understood. In order to catch up with the American productivity, the European Union pooled €9.1 billion through the Seventh Framework Programme (European Commission 2013). This funding, which is one of the largest of the programme, aims to spread the use and the research of ICT, so as to enhance the productivity of the European industry. It is worth to note that ICT appears to have an enormous effect on society, that can affect the European industry as a whole. This is one of the features that characterise general purpose technologies (GPTs).

However, ICT is not the only factor that contributes significantly to productivity growth. Many other elements like research and development (R&D) activity, human capital, and technology transfer play a fundamental role in promoting a sustainable growth.

This thesis studies further the complex mechanisms that determine the growth of TFP. By combining the results that the literature on economic growth has achieved up to the present, I test a model similar to the one designed by Griffith, Redding and Van Reenen (2004). Their model inspects the effects of technology transfer and R&D activity on the change in productivity growth rates. I modify the treatment of international trade, and I augment the research by looking into ICT investments. This last modification is the biggest variation, since I analyse the effect of the adoption of imported ICT. With this approach, I aim to capture effects which may have more latent channels of influence, that may not arise from data on total ICT investments. In particular, ICT imports may have a larger influence besides the benefits coming from its direct use and the spillovers on complementarities. Indeed, another source of spillover effect may arise from the imports of state-of-the-art ICT, with a positive impact on TFP growth. Technological progress is the result of a problem from a new point of view, therefore firms using innovative information and communications technology may apply those new approaches to other scopes. Obtaining this knowledge from the top countries in ICT production may rise productivity as the industries has among the highest growth rate of TFP. An analysis of the ICT imports may also be a proxy for the specialisation of countries. A country having a high share of ICT imports on total investments may provide several insights about the structure of the countries, and, in particular, whether there is a trade-off between two main sources of productivity growth: ICT and R&D. I test those hypotheses by means of an econometric analysis that uses country-level data for ten OECD countries for the period 2000-2007.

2. Literature Review

2.1. Endogenous Growth

The modern literature on economic growth is considered to begin in 1956, when Robert Solow and Trevor Swan presented their exogenous growth model. The coming of the Solow-Swan model dismissed the one designed by Roy Harrod and Evsey Domar, whose validity is undermined by many unrealistic assumptions, like the non-diminishing returns to capital, the constant price level, and the view of the saving rate as the reference parameter for economic growth (Solow 1956). The Solow-Swan model concentrates instead on capital dynamics such as capital deepening and depreciation, producing very different results compared to its precedent.

As Acemoglu (2009) clearly illustrates, the foundations laid by Solow are still valid today for two main reasons. Firstly, his work "makes contacts with microeconomics". The Solow-Swan model assumes that individual preferences, incentives and production processes are valid from an aggregate perspective too. In this way, you can explain long-term macroeconomic trends by means of microeconomic analyses. Secondly, it permits an empirical study of economic growth. Indeed, such adaptation of the theory allows to directly observe the factors of production that are involved in the model, so that it is possible to gather real world data from and to test the claims scientifically.

The central concept is that capital exhibits positive but diminishing marginal returns, namely the fact that as you add capital in the production process (for example machineries), any additional unit gives you a lower return. In the point where the marginal benefit and marginal cost of capital deepening balance, economy reaches the equilibrium in which growth stops. Therefore, the Solow-Swan model predicts that an economy cannot grow perpetually. For this reason, it shall not be considered as an economic growth theory, but as an illustration for transition dynamics. The model is supported by some data (see Mankiw, Romer and Weil 1992) but, as Lucas (1990) revealed, it struggles to explain the huge differences across countries. This is due to the fact that changes in output per capita are explained only by gaps in capital stock, which overestimates the importance of this factor of production in raising the living standards.

After the establishment of the Solow-Swan model, further studies concentrated on growth accounting and demonstrated that capital had only a limited role in promoting the process of growth. Productivity was proved to be the factor that determines most of the long run performance of an economy. So, the black box sneaked into the elements studied by economists and it became an endogenous variable of economic growth models.

A main turning point took place in 1986, when Paul Romer published the first endogenous growth model. "Endogenous" stands in fact for the inclusion of productivity among the variables determined within the model, instead of taking its value as given because resulting from a process outside (exogenous) the model. Despite Romer's contribution was fundamental and crucial, he could designed his model only thanks to the work of many other economists, especially Kenneth Arrow (1962). The economic implications of Arrow's concept learning-by-doing were extremely important for the evolution of the endogenous growth theory. For instance, it provided the conceptual framework to assert the increasing returns to knowledge. Conversely from capital, the accumulation of knowledge brings benefits that do not fade as its stock increases. This is given by the positive externalities that characterise it and that are linked with the concept of learning-by-doing (Griliches 1992). Some further explanation is provided later. It is important to stress that knowledge has to be viewed as a broad concept that encompasses many things like technology, inventions, ideas, abilities etc. I note this particularity other times in the thesis, but it is important that the reader grasp immediately this notion of knowledge.

The raise of the endogenous growth model shaped a new paradigm in the theory of economic growth. Moreover, thanks to the previously cited work of Romer and the one of Lucas (1988), the theory was enriched with further elements like human capital and the spillovers. Since then, endogenous growth models demonstrated not only that the rate of growth of an economy depends upon the rate of change in productivity, but they defined also the processes by which productivity grows. A more complete theory appeared in the early '90s as research and development activity was incorporated into the model. Major contributions come from Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992).

Three major conclusions are drawn from the endogenous growth theory. First of all, challenging the results of Solow, it states that an economy can experience an infinite and positive rate of growth. Second, it shows that the engine of growth is productivity, which is positively related to innovation process and technological change. Those ones are rationally undertaken for profit by economic agents. Third, it proves that, for a constant rate of growth to occur, the production of new knowledge (i.e. innovation) has to exhibit increasing returns to scale. This feature is justified by the arising of positive externalities or spillovers that characterise such good. An important policy consequences follows those results: in order to achieve growth, there has to be an active support of the sector producing innovation, that is the research and development sector. This leads governments to subsidise R&D activity, hoping to reap the benefits that the creation of knowledge brings forth, and assured by the fact that economic growth does not have a theoretical boundary.

However, the endogenous growth model is also charged with the fact that it does not fit the data entirely. One important critique was addressed by Charles Jones, who found that the growth of productivity was stagnant (or even declining) in the majority of the OECD countries, despite the R&D sector has increased a lot over the last decades (Young 1998). Jones comes to the conclusion that as technology is invented it may get harder to produce new inventions, so that you need a larger and larger number of researchers to create a constant flow of new technology.

Despite many criticisms are still advanced to the endogenous growth model (Krugman 2013 [a]), it provides you with a reasonable explanation to the growth process and it is widely used in the economic literature. It is reasonable because his focus goes on productivity, which is the element that can better explain the dynamics of economic prosperity; it is widely used because it is relatively handy to deal with it and to be systematically tested in that scientific way that distinguishes the contemporary economic research. For instance, several studies like Cameron (1998) corroborated with empirical evidence the validity of the endogenous growth theory. His research maintains that a 1% increase in R&D leads to a rise in GDP between 0.05% and 0.1%.

The next step is to understand the mechanisms operating behind the improvement in productivity. Therefore the study of growth has shifted on the promotion of productivity, looking for its profound determinants.

2.2. Determinants of Productivity

Nowadays many elements are added into economic growth theory in order explain peculiar astonishing expansions and abysmal declines that occurred in the last decades. The literature has concentrated on five main factors that are deemed to affect considerably productivity: I) indirect gains from research and development activity, II) openness to international trade and foreign direct investments, III) adoption of information and communications technology, IV) institutional settings and V) geographical characteristics and natural resources. All of them are really important to obtain a complete acquaintance with the topics in economic growth, however, their relevance depends upon different factors, like the research question and its point of view (whether it is a country-, industry-, or firm-level analysis). Therefore, their importance is not absolute, and for the purposes of my study I concentrate just on the first three elements.

The reasons for having a deep understanding of the effects of R&D on productivity growth are clear. Currently, both high- and low-income countries are transitioning to an economic system in which knowledge is the trigger to foster prosperity and to increase wealth. Its dominant position drove the specialists to name this new system as knowledge economy, and it is an established fact that the research activity is the main source for knowledge creation (García-Manjón and Romero-Merino 2012). That is the reason why a complete comprehension of R&D activity's dynamics is fundamental to analyse growth. To that end, Griffith, Redding and Van Reenen (2004) analysed the relation between R&D activity and technology transfer. Technology transfer refers to the interaction between countries with the high technological level and countries with inferior technological level. In this process the formers, known as frontier countries, transfer state-of-the-art technology to the latters, the non-frontier countries. Here technology has to be viewed in that broad sense that encompasses not merely machineries, hardware or software but also production methods, abilities and general knowledge. In this sense "technology", "invention", "innovation", and "knowledge" can be almost used as synonyms. From such interaction non-frontier countries benefit due to knowledge spillovers, i.e. indirect gains earned thanks to the benefits that characterise technology adoption and R&D activity. Knowledge spillovers are specially important when technology transfer is allowed. Indeed, by acquiring and studying advanced technology, the R&D sector of non-frontier countries can increase their knowledge. This is enabled by the development of tacit knowledge, which is a direct consequence of the learning-by-doing. Griffith et al. (2004), performing a sectorial survey on twelve OECD countries, supply empirical evidence suggesting that the higher the intensity of R&D, the easier is for a country to capture more knowledge spillovers. Therefore, they show that investments in R&D activity result in a two-fold benefit.

Before the massive focus on R&D, a broad literature inspects the influence of openness to international trade on productivity. Indeed, as maintained by Alcalá and Ciccone (2003) the idea of international trade having a positive influence on aggregate productivity is nearly as old as economics. As explained by Coe, Helpman and Hoffmaister (1997) this is the case for four main motives. The root of the first reason goes back to the XIX century, when David Ricardo conceived the theory of comparative advantage. Following Ricardo's conclusion, trade allows to allocate resources on the production of those goods for which a country has a comparative advantage, i.e. to employ resources in the most efficient way. Obviously, this improvement in the allocation of domestic resources enhances the productivity of the country itself. The other reasons stem from benefits that a country open to trade gains from the trading partners. With no barriers to international trade, the variety of products available to consumers and investors enlarge, so they can take advantage from this wider range of goods by choosing those ones that better fit their needs. Looking at the investors only, this practically means that better performing capital equipment will be available, therefore determining a raise in productivity. At the same time, state-of-the-art foreigner goods could favour productivity through spillover effects. The acquisition of new and advanced technology may lead to the creation of new products by means of imitation, readjustment or brand-new innovation. To the extent that those new goods are better performing or provide some efficiency-related improvement, the resulting outcome is a higher productivity. Finally, a subtler spillover could come from the general increase in knowledge that an innovative foreigner product may bring with it. New technology is the solution of a problem that was tackled from a perspective different to that one employed before. As long as the domestic country is able to acquire that perspective, it could use it in different applications such as company organisation and methods of production. In other terms, a country open to trade may benefit from spillovers on human capital and other capabilities that will improve the organisation of firms and the production processes. Once again, the final result is a boost in productivity. Proofs on those effects is provided by many researches such as Harrison (1994), who investigated the effect on trade liberalisation policies in Coe D'Ivoire, Pavcnik (2000), who assessed the impact of trade liberalisation in plant industry in Chile, and Eaton and Kortum (1996), that showed how trade eases the acquisition of foreign technology and how this may have a big impact on domestic productivity.

Finally, economists' interest shifted on the adoption of the so-called information and communications technology. This change is justified by the preliminary data that suggests a positive relation between ICT and productivity. For the importance of the topic on my thesis, I discuss it extensively in the next section.

2.3. The Role of Information and Communications Technology

2.3.1. Channels of Influence

Studies performed in the '80s found very scant evidence of a positive effect of ICT on productivity; "Computers were everywhere but in productivity statistics", Solow stated. Much of those studies suffered from data problems, since the quality of the sources were not very reliable at that time (Pilat 2004).

A serious problem at the beginning of the research regarded the measurement of the ICT, due to the specific features of the technology. Statistics about hardware, software, data communication instruments, etc. need continuous and frequent quality-adjustment in order to provide reliable results about their economic impact. This necessity is due to the fast technological change that characterises the production of the ICT manufacturing industry, notoriously represented by the Moore's Law. The usual techniques applied to normal durables to compute their depreciation needed to be revised, but despite such revision occurred it is still hard to determine perfectly the actual value of ICT goods. Many of the advantages that emerge from ICT adoption regards characteristics like quality, speed, reliability, and variety of products and services, elements whose current statistical measures struggle to take into account. As a consequence, the assumption stating that the price reveals the true benefit of products may not hold for ICT. Another reason that caused troubles in estimating a beneficial effect of ICT was the fact that, like the larger share of innovation that takes time for its advantages to be absorbed, ICT's benefits did not arise immediately (Bosworth and Triplett 2007, Krugman 2013 [b]). This aspect holds particularly for such technology, whose influence may be highly affected by many issues such as the requirement of complementary changes and adjustment costs. When undertaking country-level studies (and to some extent those at industry-level too) the problem is exacerbated even more, since effects appear when their impact is wide and strong enough to be visible at the aggregate level. Brynjolfsson and Hitt (2000) show that the growth of TFP associated with investments in ICT is observed with a delay between four and seven years, although nowadays this timing may have reduced considerably.

Those problems led earlier studies to prove a little contribution of ICT to productivity growth, whose results were also featured by large variance, especially at the firm-level (Biagi 2013). This last aspect is justified by the complexity of adopting ICT successfully. Investing in ICT is not a trivial issue, since to ensure of high returns managers have to invest strategically. The large variance demonstrates that many managers failed in this task.

Today part of those difficulties have been overcome, and after three decades of research, ICT has been found to influence productivity through three main channels: capital deepening, benefits to complementary elements, and spillover effects. Those channels can be grouped into two categories, depending on whether the effect is directly or indirectly transmitted to the growth rate of productivity. Capital deepening falls in the first category, whereas benefits to complementary elements and spillover effects foster productivity in an indirect fashion.

Direct Channels of Influence

Primarily, information and communications technology may have a positive effect on the growth of productivity through capital deepening. This leads to a larger amount of capital per worker which increases the efficiency of the production process.

To understand the theoretical base that identifies this distinct impact of ICT on TFP, I apply the standard neoclassical approach, starting from the usual production function. I begin from the production function as it is the fundamental mathematical tool used to study economic growth. Basically, the production function is an equation that tells you how many goods can be produced given certain amounts of inputs (factors of production). The two fundamental inputs are labour and capital, where labour is the number of workers employed (or number of hours) in a specific period t and capital is the stock of durables (machineries, buildings, etc.) used in the production process. Following those guidelines the production function of country *i* in year *t* takes the form:

$$Y_{it} = F(A_{it}, K_{it}, L_{it}) \tag{1}$$

Where *Y* is the quantity of output produced, *K* is the capital, *L* is the labour and *A* is the technological level that determines the productivity of all the production factors employed in the production process. Thus, the variable A is the total factor productivity.

Equation (1) is the pillar of the neoclassical production function, which was highly criticised by the neo-Ricardian school (also known as Sraffian school). For almost twenty years, neoclassical and neo-Ricardian economists debated the validity of such equation to represent the entire outcome of the economic system. Called with many names such as “the two Cambridges debate” and “the capital controversy”, such debate is described by several articles like Cohen and Harcourt (2003). Two main personalities that supported the production function were the Nobel Prize-winner economists Paul Samuelson and Robert Solow. On the other side, Joan Robinson and Piero Sraffa pointed out the inconsistency of such approach, which implied a direct use of microeconomic concepts to macroeconomics. Despite of the many criticisms addressed by the neo-Ricardians were embraceable, the production function is still used in economics for its usefulness.

Equation (1) can be better specified by assuming a particular shape of the relations between inputs and output. Following the standard approach, I pick the Cobb-Douglas production function. The equation was designed by Charles Cobb and Paul Douglas in the first half of the 20th century and takes the form:

$$Y_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta}$$

Where α and β are the output elasticities with respect to each input, whose sum determines the returns to scale of the production function.

This form of the Cobb-Douglas production function is the starting point to analyse the growth rate of output. Such study is performed through the earlier mentioned growth accounting, which is an analytical method developed by Solow (1956) that allows you to identify the determinants of economic growth. Specifically, growth accounting takes the production factors one by one and it looks into their relation with the output and the other variables (Barro 1998).

In order to proceed I transform first the equation in a logarithmic one. By doing so there are some important consequences: you can easily perform an analysis across time in order to study the change in value of each factor from t-1 to t, and the exponentials become parameters constant over time. Writing it in intensive (namely per capita) terms you obtain:

$$lny_{it} = lna_{it} + \alpha lnk_{it}$$

Where the lower case letters stand for variables in per capita terms, i.e. y = Y / L.

To analyse the growth rate of each factor from t-1 to t I compute the difference between the two time periods. Knowing that the difference between such logarithms is, for small figures, equal to the rate of growth of the variables themselves, I can replace the natural logarithm with the rate of change Δ. Furthermore, following Aghion and Howitt (2007) who apply the standard neoclassical approach, I observe α through the share of capital in the production factors. This last passage is of fundamental importance for the growth accounting exercise, and it is also the source of the main criticisms advanced to it. Indeed, the actual value of the contribution of production factors to the creation of output are not directly observable. The theoretical consideration of α as the contribution of durables employed in production needs a proxy, so as to be measured and employed in the computational tasks. Some assumptions coming from the neoclassical tradition help you to define such proxy. The main ones, asserts that the economy is characterised by perfect competitive markets where rational agents operate. This (big) simplification enables to assume that firms invest according to the cost-benefit principle, which maintains that capital is accumulated up to the point in which its marginal cost equals its marginal productivity. If this holds true, then the contribution of capital can be valued by its accounting share, so that it becomes directly observable. Unfortunately, this nice assumption is rarely satisfied. Other assumptions regard other topics, like the absence of measurement errors. Nevertheless, growth accounting remains a useful tool to assess the composition of the output growth and it provides hints on the dynamics of production factors. Therefore, the literature takes those assumptions for true, and it substitutes the parameters α with s_K, which represents the share of capital employed in the production activity. Therefore, equation (2) can be written like:

$$\Delta y_{it} = \Delta a_{it} + s_K \Delta k_{it} \tag{3}$$

Equation (3) maintains that three factors contribute to the growth rate of output per capita: I) the growth rate of the total factor productivity a; II) the growth rate of the capital deepening k; III) the share of capital on production.

An example may clarify the role of the TFP and its interaction with the increase in the capital-labour ratio. Suppose that you purchase an update of your storage management software, which it boosts the performance of the same storage operations thanks to a reduction by one quarter of the time. This new benefit is the result of a technological change, i.e. an increase in knowledge (the new understanding on how to manage the storage) that comes from the R&D activity of the software company. However, the purchase of the update rises the contribution of capital deepening, that shows up as an increase in k. Nevertheless, suppose that the price you pay for the new version is lower than the additional marginal productivity of which the software is now endowed. In this way, the output experiences a boost in the rate of growth not explainable by the increase in capital deepening only. The residual gap between the two increments will then appear in the growth rate of technology, namely in A, which brings the economy to a higher level of technology. As I previously described, you can get this jump towards a more efficient production it by observing the TFP.

Rearranging equation (3) you can see this aspect, by focusing on the TFP you get:

$$\Delta a_{it} = \Delta y_{it} - s_K \Delta k_{it} \tag{4}$$

Equation (4) is known as the Solow residual and gives you two main results. First, it provides a method to compute the rate of growth of TFP, and second, it shows the relevance of capital in explaining the dynamics of the productivity. Despite the problems related to this method, like

Barro (1998) points out, growth accounting is a useful tool needed to assess the factors' contribution to the rise in output per capita and it is extensively used to determine the TFP.

However, if you keep one unique variable for the capital stock, you cannot account for the heterogeneity of capital goods and the differences that characterise different investments. That is, you need to modify (4) in order to reckon those stark differences between ICT capital and non-ICT capital since, as I previously explained, different techniques of depreciation and quality-adjustments are applied. This is performed by splitting the variable k in the two variables k and c; which represent respectively the stock of non-ICT capital and the stock of ICT capital. Isolating that part from the rest of the investments, you can distinguish the effects that each component produces on the TFP. Following this reasoning, the Solow residual that you obtain is:

$$\Delta a_{it} = \Delta y_{it} - s_K \Delta k_{it} - s_C \Delta c_{it} \tag{5}$$

With equation (5), the amount of ICT per capita adopted c and its share s_C enter into the determination of the rate of growth of technology.

There is abundant empirical literature based on the growth accounting method which confirms the significance of ICT on TFP growth. For instance, several studies investigating the gap in productivity between U.S. and Europe, such as Colecchia and Schreyer (2002), Oliner and Sichel (2002), Inklaar, Timmer and Van Ark (2007), and Jorgenson and Timmer (2011), address the gap in ICT investments and share of firms producing ICT that Europe suffers as the reason for the differences between the two growth rates. Specifically, the above mentioned paper by Colecchia and Schreyer finds that the ICT capital deepening was responsible for a share between the 30 and almost the 100 percent of output growth in United States, Canada, Australia and Finland. Figure 1, taken from Corrado, Haskel and Jona-Lasinio (2014), gives a clear insights of this positive relation.

This method is particularly suitable to assess the contribution of ICT capital on the ICT producing sector. Indeed, in Biagi (2013) it is shown that large part of the TFP growth in U.S. was to be attributed to the semiconductor industry, which is featured by massive R&D activity, innovation and technological progress. However, the ICT using sector is the one that employs the higher amount of ICT capital, and you cannot overlook the positive effects that ICT may exert on

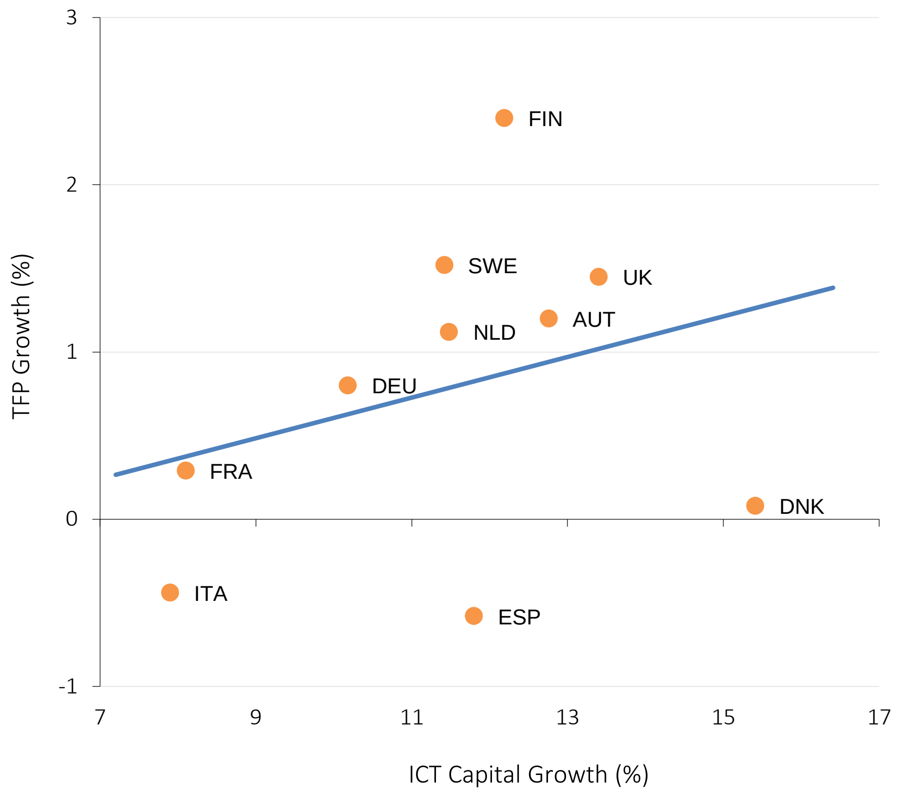

Figure 1. Relation between ICT capital growth and rate of change of TFP for ten European countries. Source Corrado, Haskel and Jona-Lasinio (2014)

this side of the economy. Unfortunately, the service sector, which is the industry that employs the largest share of ICT products, is particularly complex to analyse. As I previously said, ICT capital goods promote enhancements such as quality, variety and velocity of its products are difficult to be absorbed in the market price.

Indirect Channels of Influence

Besides the direct benefit that investments in ICT ensure, the literature has found large evidence of positive effects that go beyond this straight relation. This is given by the fact that ICT is usually viewed as a general purpose technology (GPT), namely an innovative good that (I) is widely employed throughout the economy (both in production and consumption), (II) improves the efficiency of the current production processes and (III) triggers the creation of new products, services and business methods (Bresnahan 2010). These last two features can be rewritten by stating that, for a technology to be a GPT, it has to enable substantial innovational complementarities. In fact, many studies maintain that the stellar returns from ICT is highly correlated to those complementary adoptions, which absorb the spillover effects arising from ICT capital.

If ICT is truly a GPT, it is associated with considerable spillover effects. This consideration is supported by the so-called structuralist view, which sees in Richard Lipsey a leading figure, and which believes that ICT enables the spread of benefits throughout the economic system. With the adoption of ICT new profitable opportunities are available and new innovations are promoted (Carlaw and Lipsey 2003). Some criticisms are advanced to this approach. A main example is given by Robert Gordon, who states in a recent study (Gordon 2012) that ICT cannot be considered a GPT and that large part of the benefits that this technology embeds have already run out.

Despite some scepticism, ICT is considered to be a factor that brings with it important spillover effects that are likely to have effects of main importance on growth. Specifically, the research has identified three main areas where ICT may allow higher gains in productivity. First of all, a successful adoption of ICT is likely to bring changes on organisation methods and company processes, ranging from external relation procedures to production activities. Second, the use of ICT favours the enhancement of employees' skills, with a consequent raise in human capital. Finally, some evidence suggests a positive interaction between ICT adoption and R&D's returns. Unfortunately, those results may suffer of endogeneity bias, as many empirical studies point that ICT allows gains in productivity only if it is accompanied by further improvements and investments in other fields.

Organisational innovation is associated with the implementation of advanced business practices and innovative production processes, which leads to efficiency gains thanks to cost savings and quality improvements. These days the importance of this element in firms have got such a relevance that the literature coined the term organisational capital, which indicates all the practices related to business organisation. A recent paper by Marin, Schymik and Tscheke (2015) shows how the great success of Germany's, Austria's and Spain's exports has to be attributed to their investments in organisational capital. The increase of their trade outflow is led by a rise in the quality of the product, which is the result of advanced business practice, like for instance decentralisation of decision making process and more engagement of workers to management choices. Investments in computers, management software and general ICT may speed the process up and they are likely to increase even more the savings resulting from reorganisation. Moreover, ICT provides better information and computational tools that permit managers and employees to take quicker and more effective decisions. Many empirical results prove a positive relation between those two elements. The previously cited study by Brynjolfsson and Hitt (2000) provides one of the most important piece of this strand of literature, showing that ICT not merely promote reorganisation but it also enables new work practice, boosting significantly the productivity of firms. Gretton, Pali and Parham (2004) perform a sectoral-level analysis on the Austrialian industries and they find significant correlation between the adoption of ICT and complementary reorganisational activities. The acquirement of information and communications technology was usually linked to structural company changes aimed to approach new managerial procedures and methods of production. Another study from Crespi, Criscuolo and Haskel (2007) on UK firms supplies further evidence of a relevant interaction between ICT and organisational factors. Finally, Hall, Lotti and Mairesse (2010) demonstrate how most of the Italian firms that undertook investment in ICT combined them with changes in business practices and methods of production, thus indicating the strong complementarity of the two factors.

Turning to the human capital, its positive link with growth is widely accepted. The development of the theory of human capital helped to insert this concept into economic growth analysis, and the research proved its predominant role. As Mincer (1981) illustrates, average levels of income are much more strongly correlated with human capital than with physical capital per capita. Moreover, it appears that a high endowment of human capital stock plays a twofold effect on economy, since it both originates and is originated by economic growth. Increase in human capital favours a boost in physical capital's marginal productivity, and at the same time, growing of physical capital raises human capital's marginal productivity. As you saw, human capital was one of the first element to be added into endogenous growth models. More importantly, recent literature demonstrated that human capital is a main factor associated with ICT accumulation. Actually, most of the studies on spillovers of ICT focus both on changes in company structure and on increase in employees' skills, and like for the relation between ICT and organisational change, the connection between ICT and human capital is grounded on efficiency gains. The connection between the two elements is given by the fact that workers who employ those technologies gather new abilities thanks to the acquisition of tacit knowledge. The learning-by-doing enhance their skills, in turns this leads to a raise in productivity. At the same time, the use of ICT requires highly skilled workers, and the literature coined the term skill-biased technical change to illustrate the phenomenon by which firms who shift to an intensive adoption of ICT demand higher educated workers. Products like computers and software enable the allocation of human work on more intellectual tasks, leaving repetitive and mechanical operations to machines. This case holds not only for blue collar workers, but for white collar ones too. Nevertheless the results are not so homogenous, as some research concludes no complementarities between the two elements. For example, the previous cited paper of Hall et al. (2010) finds no clear interaction between the two elements. Also Melville, Kraemer and Gurbaxani (2004) show that a direct link between ICT and human capital is not clear-cut.

Finally, some evidence suggests a positive relation between ICT adoption and R&D activity's returns. Theoretically, the benefit may flow on both directions: on the one hand ICT gives new tools to researchers and favours efficiency, thus new innovation is produced more easily and productivity goes up; on the other hand R&D activity could result in innovation to be applied on existing technology, or could have some spillovers that affect positively the use of ICT, inducing an eventual raise in productivity. In any case, ICT and R&D are two acronyms that may be closely related and that may be mutually beneficial. Nevertheless, the literature on this aspect produced conflicting conclusions. The study previously cited by Hall et al. (2010) demonstrates that ICT has a weaker and less significant role in the innovation process compared to R&D investments. Indeed, despite the lack of such investments forbids any promotion of innovation (so that ICT is a required tool to attain new discoveries), massive investment in it does not raise the probability to innovate. Therefore, their study maintains that they exert their influence through different channels. On the contrary, the previously mentioned research by Corrado et al. (2014) finds that the combination of ICT adoption and R&D activity favours beneficial complementarity of the two elements. Not only they both promotes an increase in productivity, their joint use rises each other returns.

2.3.2. Channels of Acquisition

The discussion on ICT has demonstrated its relevance on the rate of growth of productivity. At this point, a question may rise; evidence confirms that the implementation of ICT affects positively the productivity of countries, what about its production? This question can be reformulated focusing on the source of ICT capital good demanded: a firm willing to invest in ICT faces a trade-off between the acquisition of ICT domestically produced or to import it, does this choice affect the growth of TFP? Conceptually the two options have both benefits and disadvantages.

As some empirical literature warns, the European slowdown in productivity may be also caused by the fact that there is little share of firms producing ICT technology. From this point of view, the lack of a strong ICT producing industry may have serious drawbacks. The presence of a solid ICT industry could be important for a concept that I have already discussed, namely knowledge spillovers. The importance of those positive externalities is well established and their lack could bring severe drawbacks on. Indeed, the industry of ICT produces state-of-the-art technology whose benefits may spill over the mere use of the products. This industry experiences normally high rates of technological progress and often larger growth rates of productivity than other industries. The concentration of such effects may have beneficial results on the overall economy, and some empirical evidence demonstrates such link. Figure 2, taken from Pilat, Lee and Van Ark (2003), shows that expansions or shrinkings of ICT producing sector (in the figures those in blue and orange) are usually related with boosts or declines in productivity. Except for Germany the relation holds, as you see a declining in Danish TFP as the ICT industry reduces, whereas you observe for the rest of the countries an enlargement in the ICT producing sectors and a raise in productivity.

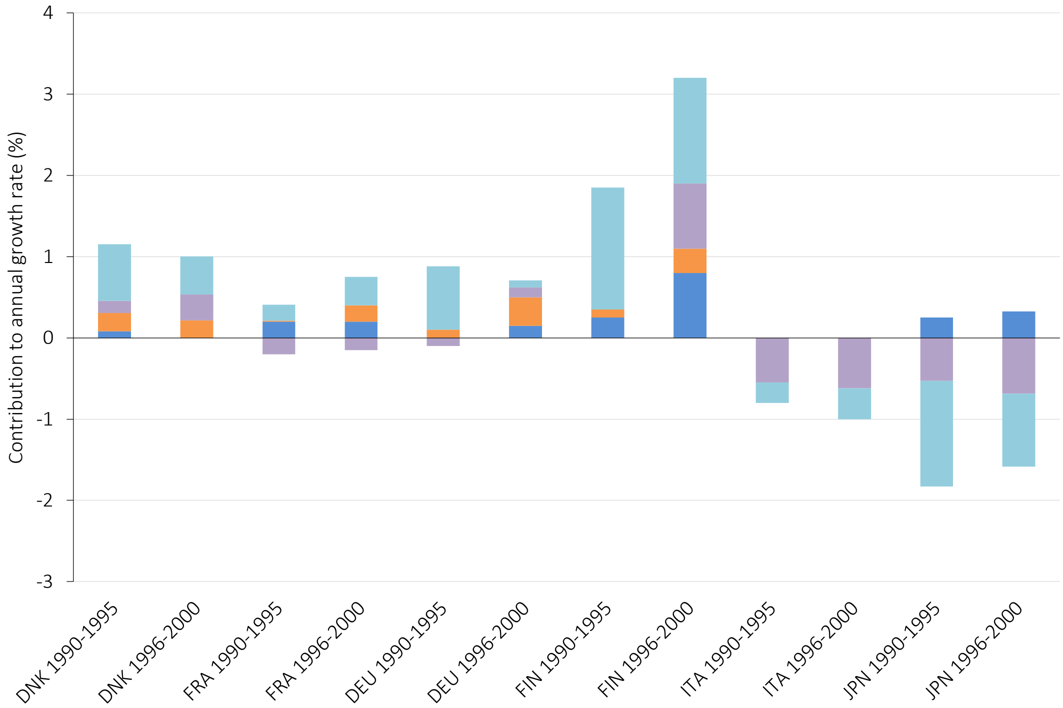

Figure 2. Contribution of key sectors to TFP growth between 1990-1995 and 1996-2000. Source Pilat, Lee and Van Ark (2003). The series represents the following sectors: in dark blue is the ICT producing manufacturing, in orange the ICT producing services, in purple the ICT using services, in light blue other activities not included in the previous categories.

Moreover, as Baldwin and Diverty (1995) shows, the ICT industry requires a relevant stock of human capital as it needs high-skilled workers to operate. Without an ICT industry that demands highly educated employees, the incentives for people and institutions to invest in human capital may fail, causing detrimental effect throughout the economy. Brain drain is another side this issue, since it moves the returns from investments in human capital to those locations where ICT producing firms operate. A recent research from Koutroumpis, Leiponen and Thomas (2015) addressed the difficulty to keep European talents in ICT field from migrating to U.S.A. as one main question to secure the prosperity of such industry in Europe.

On the other side, little share of firms producing ICT and the consequent need to import the technology could have positive influence too. Recalling a classical concept, countries do not need to manufacture all the goods they want to consume, rather they should specialise on the production of those for which they have a comparative advantage. If European countries are not producing ICT it could be the case that they are specialising on manufacturing other goods that they can produce more efficiently. Therefore, concentrating on ICT could in reality worsen the productivity performance of Europe, since it would not allocate resources in the most productive way. From this perspective, policies that aim to structure a solid ICT industry may actually cause damaging a misallocation of resources.

Another benefit, which follows the reasoning for general international trade, is that high imports of ICT may represent the use of better performing products. This would be permitted by a widening of the market for ICT, so that the supply of the technology gains from higher variability of goods and heterogeneity of producers. This may be especially true for ICT due to its rapid technological improvements and the fierce competition of the industry.

Finally, the imports of ICT may bring significant spillovers effect on domestic industries. As I previously said, technological progress is the result of a problem from a new point of view, therefore firms using innovative information and communications technology may apply those new approaches to other scopes. Obtaining those knowledge from the top countries in ICT production may rise productivity as the industries has among the highest growth rate of TFP.

Thus, the choice between producing and importing ICT may tell us some important links between the growth of productivity and the openness of a country on technological trade. Whether the firms of a country decide the former or the latter option would be determined by the feature of the ICT industry of the country. Moreover, the two choices could cause many elements to arise, affecting the overall economy.

3. Model and Specifications

3.1. The Model

Several results emerged from the literature previously discussed. In this section I summarise them while designing the empirical model to be tested.

First of all, section 2.2. showed that research and development activity is the core source of productivity growth and its consideration in studying its dynamics is fundamental. Furthermore, the acquisition of tacit knowledge was proved to arise from R&D activity, so that the R&D boosts the growth rate of TFP through two channels. Besides the direct positive effect given by the production of innovation, an indirect positive effect is due to the facilitating of technology transfer. The inclusion of a parameter explaining the benefits that a country gains from this gap between the frontier is necessary, and to capture the additional gains from investing in R&D it, I interact it with the R&D parameter. The same reasoning follows for human capital, following the model by Griffith et al. (2004) I consider it as source of productivity growth too and in order to estimate the benefits that can arise from the disparity in productivities I relate it with the technology transfer parameter. Taking into account those elements, the starting point of the model is given by:

$$\Delta lnA_{ijt} = \rho_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \rho_2 H_{it-1} + \rho_3 ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + \left[\delta_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_2 H_{it-1}\right] ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + u_{ijt} \qquad (1)$$

Where *ΔA* represents the rate of growth of productivity of industry j of country i at time t, R/Y is the intensity of R&D investments on the value added, H is the stock of human capital, A_F/A_i is the element explaining the technological transfer, measured as difference between the productivity of the frontier (F) and that one of the non-frontier country (i), u is an error term.

For what regards ICT, as I explain in section 2.3., I regard the import of this technology as interest of analysis. The additional benefits that the imports of ICT may have compared to the adoption of domestic ones require decomposing the amount of ICT invested according to the source of production. Besides its direct contribution for the growth of TFP, I take into account the literature considering the complementarities of ICT. This leads me to include the element as an indirect driving force to boost productivity, interacting ICT imports with R&D and human capital. Indeed, on the one hand, those factors can raise their returns thanks to the use of ICT, and on the other hand, they also seem necessary to gain considerable returns from ICT investments. I do not consider the organisational innovation because, as suggested by Pilat (2004), little evidence can be found from a perspective higher than the firm-level. From industry-level data, organisational factors are likely to not appear in the tests. To assess the role of imports I will control for domestic ICT and total investment of ICT, so as to assess whether the source of the ICT adopted counts from productivity dynamics. Considering all those apsects, the equation turns to:

$$\Delta lnA_{ijt} = \rho_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \rho_2 H_{it-1} + \rho_3 ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + \rho_4 ln\left(\frac{ICT^{IMP}{}_i}{I_{ij}}\right)_{t-1} + \left[\delta_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_2 H_{it-1}\right] ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + \left[\delta_3 ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_4 H_{it-1}\right] ln\left(\frac{ICT^{IMP}{}_i}{I_{ij}}\right)_{t-1} + \chi_{ijt} + +u_{ijt} \tag{2}$$

Where ICT^{IMP}/I represents the intensity of ICT imported on the total investments, with this parameter I aim to determine the relevance not merely of the use of the technology, but also the importance of the internationality of the industry regarding its investments, hoping to capture those spillovers that an international technological trade may provide. The variable χ represents a control variable for total ICT investments, specifically it is equal to:

$$\chi_{ijt} = \rho_3 ln\left(\frac{ICT}{I}\right)_{ijt-1} + \delta_5 ln\left(\frac{ICT}{I}\right)_{ijt-1} ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_6 ln\left(\frac{ICT}{I}\right)_{ijt-1} H_{it-1}$$

Finally, the error term u includes a country fixed effect ψ, an industry fixed effect ϑ, a time fixed effect T, and an uncorrelated error ε, so that is given by:

$$u_{ijt} = \psi_i + \vartheta_j + T_t + \varepsilon_{ijt}$$

Therefore, the final model to be tested is:

$$\Delta lnA_{ijt} = \rho_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \rho_2 H_{it-1} + \rho_3 ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + \rho_4 ln\left(\frac{ICT^{IMP}{}_i}{I_{ij}}\right)_{t-1} + \left[\delta_1 ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_2 H_{it-1}\right] ln\left(\frac{A_{Fj}}{A_{ij}}\right)_{t-1} + \left[\delta_3 ln\left(\frac{R}{Y}\right)_{ijt-1} + \delta_4 H_{it-1}\right] ln\left(\frac{ICT^{IMP}{}_i}{I_{ij}}\right)_{t-1} + \chi_{ijt} + \psi_{ij} + \vartheta_j + T_t + \varepsilon_{ijt} \tag{3}$$

Equation (3) states that the rate of change of TFP is determined by five parameters and the interactions among each other. Graphically, the model can be represented with the following diagram:

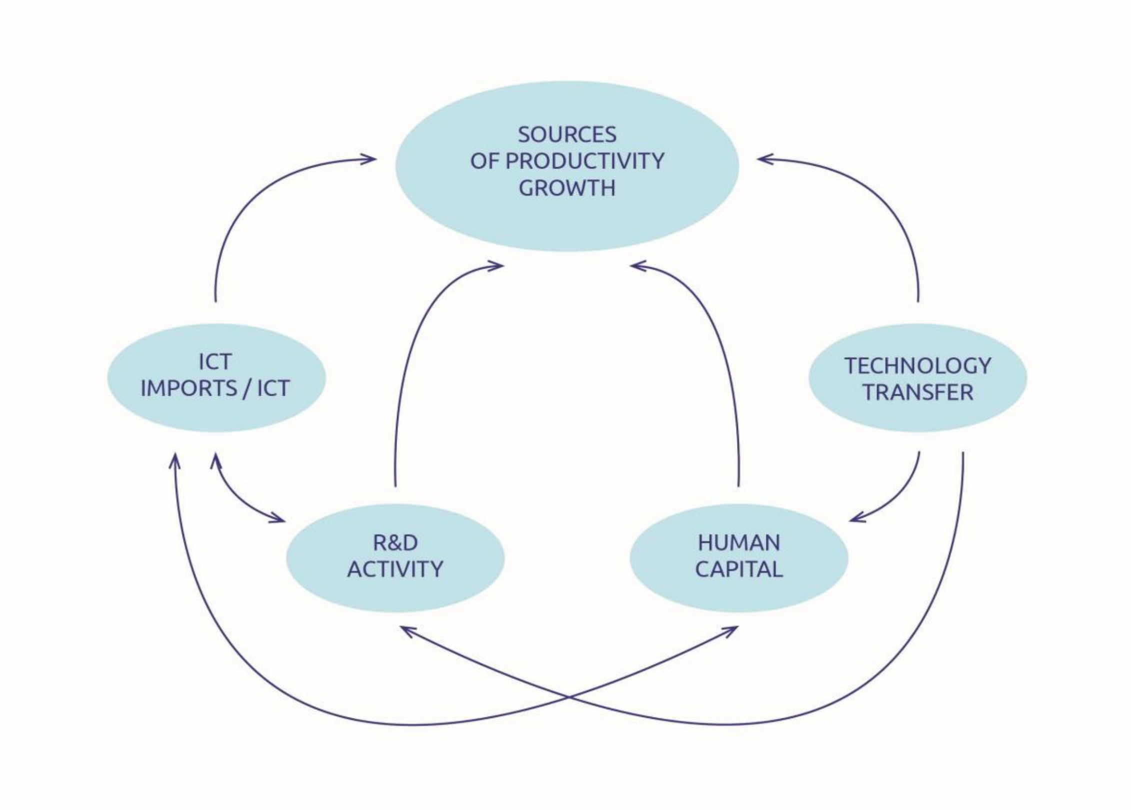

Figure 3. Diagram of the model. It shows that there four main elements which affect directly the growth of productivity. However, there is a complex interrelation among those factors, which could affect each other and improve the effect on productivity growth.

3.2. Frontier, Identification Strategy and Endogeneity

Some issues have to be faced in this empirical test, ranging from the variables employed to the econometric technique. For what regards the variable, the main problem is to estimate a correct measure for the technological frontier. Depending upon its definition and the analytical methods used one can get different results based on the same dataset. Issues about econometrics are due to the technique employed, that is the Ordinary Least Squares (OLS), which has important advantages but also some downsides.

3.2.1. Frontier

As previously explained, the technology frontier is generally defined as the country or the set of countries which are the forefront of the technological progress. This is usually done by computing the productivities of countries and picking those with the highest levels as frontier. However, the frontier can be identified for simplicity in one country, indexing productivity of the rest of the non-frontiers to the one of the selected country. This procedure is used by a large share of the literature and the frontier is usually defined as the U.S.

However, other studies use a definition of frontier that is not attached to any specific country, rather it is given by the country with the highest TFP on each specific period, usually one year. This approach, used by Griffith et al. (2004) too, has important advantages. First, you allow for changes on the frontier across the years depending on the most productive countries. This gives a more reliable measure.

Following this approach, the rate of growth of TFP is measured as the change in the Solow residual from time t-1 to time t. The transformation of the production function into a traslog equation circumvents some technical issues. Thus, the change in TFP is given by:

$$\Delta A_{ijt} = ln\left(\frac{Y_{ijt}}{Y_{ijt-1}}\right) - \frac{1}{2}(\alpha_{ijt} + \alpha_{ijt-1})ln\left(\frac{L_{ijt}}{L_{ijt-1}}\right) - \left[1 - \frac{1}{2}(\alpha_{ijt} + \alpha_{ijt-1})\right] ln\left(\frac{K_{ijt}}{K_{ijt-1}}\right)$$

Where Y is the value added of industry j of country i at time t, α is the labour share, L is the number of hours worked/total workers and K is the stock of capital. Computing the TFP growth with this method and compare it across country has, however, some drawbacks to take into account. Data need to be adjusted in order to get perform a cross-country analysis, like for instance skill levels, markups, etc. Specifically, data on labour share present high volatility also due to difficulties in measuring it. By employing a transcendental logarithmic function I aim to reduce the errors that flawed data on α could bring.

The distance from the frontier is measured as the difference between the TFP levels of the frontier and the non-frontier countries:

$$\frac{A_{Fjt}}{A_{ijt}} = GapA_{ijt} = MA_{Fjt} - MA_{ijt}$$

Where MA_{ijt} is the level of TFP relative to the geometric mean of all the TFPs of industry j for all the countries, that is:

$$MA_{ijt} = ln\left(\frac{Y_{ijt}}{\bar{Y}_{jt-1}}\right) - \frac{1}{2}(\alpha_{ijt} + \bar{\alpha}_{jt-1})ln\left(\frac{L_{ijt}}{\bar{L}_{jt-1}}\right) - \left[1 - \frac{1}{2}(\alpha_{ijt} + \bar{\alpha}_{jt-1})\right] ln\left(\frac{K_{ijt}}{\bar{K}_{jt-1}}\right) \qquad (4)$$

The barred variables are the geometric means of industry j at time t for all the set of countries. This is a sort of weighing that ensures a better measure of the level of productivity.

3.2.2. Identification Strategy and Endogeneity

The estimation technique that I employ is the ordinary least squares (OLS). This method is a common tool used to predict the relations between the independent variable and the explanatory variables. The principle followed by this technique is to minimise the squares of the residuals. It has several advantages, despite if not used carefully you may run into severe problems.

Endogeneity is one of the main problems for this empirical test. Biases caused by endogeneity are due to the fact that the explanatory variable is affected by the variable it explains. Practically, it means that if R&D has an endogeneity bias towards the TFP growth rate, it means that R&D, besides influencing the growth rate of the productivity, is also influenced by the growth of TFP. This leads to wrong results that jeopardise the validity of the regression, and unfortunately both my parameters for R&D and ICT are touched by this issue.

Few ways are available to cope with this problem, which are not always applicable. The main solution for ruling endogeneity out is to employ instrumental variables, i.e. a variable that affects R&D or ICT (so it can be used as a proxy for its changes) but that has not got any influence on productivity. Unfortunately the literature has not found yet any solid instrument neither for R&D Griffith et al. (2004) nor for ICT (Draca et al. 2006). To limit the endogeneity one solution may be to use lagged amounts of R&D and ICT stocks by one period ahead.

3.3. Data Description

The data employed to perform the empirical test come from four different sources. The OECD Structural Analysis (STAN) database provides data for thirteen industries of ten OECD countries from 1994 to 2007. The variables given by OECD STAN are value added, R&D expenditure, number of workers and hours worked, labour share and total value of investments. Missing data (especially for the hours worked) were filled with those provided by EU-KLEMS, so as to obtain a panel data as balanced as possible. All the measures were expressed in current prices of the local currency. EU-KLEMS supplies also the amount of ICT invested in each industry, while the World Bank database gives data on ICT imported. Unfortunately this last source does not give industry-level data, but contry-level only. Finally, from Barro and Lee (1994) I obtain data at the country-level for education.

The countries studied are Austria, Czech Republic, Denmark, Finland, Germany, Italy, Netherlands, Slovenia, Sweden and United States of America. The rest of the OECD countries that are not taken in considerations did not meet enough data requirements from the dataset employed. For the same reason, I consider only certain industries among those provided by the dataset and I had to group together some industries in order to have a dataset as more complete as possible. For instance, I had to choose a bigger category for service industries than for manufacturing. In particular, the industries I analyse are: agriculture, hunting and fishing; mining and quarrying; food products, beverages and tobacco; textiles, textile products, leather and footwear; wood and products of wood and cork; pulp, paper, paper products, printing and publishing; chemical, rubber, plastics and fuel products; other non-metallic minerals; basic metals and fabricated metals; machineries and equipment; electricity, gas and water supply; construction; finance, insurance, real estate and business services. The decision to choose an analysis at the industry-level is supported by the data I am dealing with and the effect that I want to inspect. Indeed, by treating variables like R&D expenditure and ICT adoption, a sectoral analysis is required. Indeed, as I previously hinted, the estimations of those elements is likely to vary greatly among different industries. Second, I conduct the estimation on an industry-level because it provides the best compromise between sources since I focus on imports and spillovers and data.

The variables observed are elements commonly analysed by the empirical literature, however some attention has to be taken regarding the human capital, the ICT and the TFP.

Indeed, the measurement of human capital is a tricky topic and the debate about it has not yielded yet a definitive proxy. Three main approaches are used by the current literature: the cost-based approach, the income-based approach and the education-based approach. Supported by the study of Le, Gibson and Oxley (2005). I take as measure for human capital the share of the population with the higher (tertiary) education to the total population. I choose higher education because it is a more relevant measure of human capital for OECD countries than secondary education (Griffith et al. 2004).

Also regarding ICT the research faces often many problems related to the availability of data. To construct confident aggregate measures of ICT investments is a hard task. Indeed, the usual methodology is grounded on assumptions that are not always reliable, due to the characteristics of the assets. One reason is that the technologies under the label ICT are very different among them and the rapid technological change of such goods makes the construction of aggregate data even harder. Some problems can be mitigated if you use firm level data on ICT investments expenditure, as suggested by Hitt, Hall, Lev and Brynjolfsson (1995). Such measure is the best proxy to use in order to study the ICT influence on productivity since it has three main advantages: I) it can be directly included into the production function; II) it is easy to measure; III) it is strongly correlated with the data at firm-level on capital stock. I follow this approach by taking expenditure on ICT imports. Then, this value is taken relative to the total amount of investments.

My estimation of the frontier is performed following (4) in which I plugged in two slightly different dataset. Indeed, as I previously pointed out, to create a balance the panel data as much as possible I recover data for hours worked from different sources. Specifically, the data from US was not available in OECD STAN, so that I obtain that information from EU KLEMS. However, the two sources provide different values for the same countries (although the difference among countries and the evolution of the element is the same), meaning that the two dataset are constructed with different approaches. Therefore, the construction of the frontier through that dataset may not reveal the true differences among countries, which has a crucial role in this calculation. To face this issue I consider another kind of data, the total employment that is found for all the countries analysed in OECD STAN. Unfortunately, this measure is regarded as a less precise indicator for labour input, so that I could define a frontier that may not be as accurate as one that is obtained by means of hours worked. Despite this inconvenience, the TFP levels I computed with the two different measures do not exhibit enormous differences. Figure 4 shows the TFP levels of the ten countries analysed for the industry of basic and fabricated metals. On the right you have the measure that considers the hours worked, whereas on the left you have the productivity levels computed with the total employment.

It is clear to see that the two charts show equal trends, despite the levels of TFP with hours worked exhibits a frontier more crowded than those computed with total employment. Moreover, this leads to several switches leading country across the years, that is, the TFP levels obtained with the hours are higher for the best performing countries. In this specific case, the measure is inflated for Austria, Finland, Germany and Netherlands. On the other side, the TFP levels determined with the total employment exhibit a unique frontier for the whole time frame, which is the United States. This is visible for most of the other industries, so that the measure that reckons for the hours worked produce more diversified frontiers than the one that counts for total employment. As a consequence, the former exhibits the Netherlands as most efficient country being 76 times at the frontier in 169 periods, whereas the latter sees the U.S. as the leader with 90 entries as frontier.

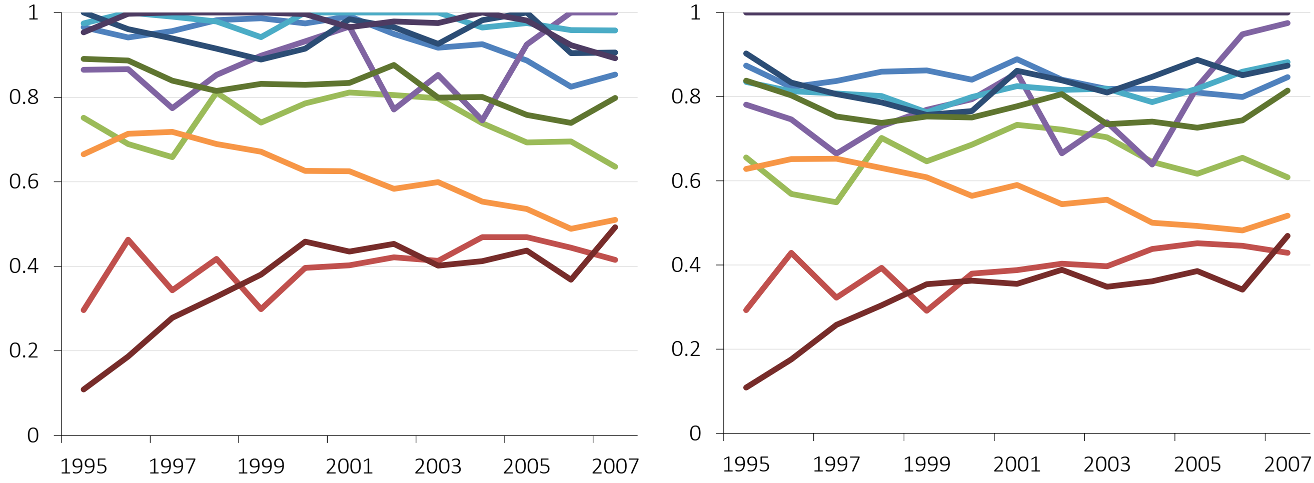

Figure 4. Levels of TFP considering hours worked (on the left) and total employment (on the right). Source: author calculations.

Despite the measure of the total employment may be less accurate, the fact that it comes from a common source provides a more reliable baseline for my analysis. Running the regression with the TFP computed with the total employment gives better results too, thus it is the measure that I regards as TFP for the rest of thesis. Table 2 summarises the frontier countries for each industry. The table indicates that the United States is the most productive country in the sample analysed, leading 9 industries out of 13. At the same time the Netherlands reaches the second position, being the frontier of 3 industries. It is important to note that the countries which are pointed as leader or second leader could not be in that position for the all period considered. Indeed, some industries experienced different frontier between 1995 and 2007.

Industry	TFP Level	Country	Industry	TFP Level	Country
01-05	First	Netherlands	26	First	Netherlands
	Second	United States		Second	United States
	Mean	0.6802		Mean	0.7314
10-14	First	Netherlands	27-28	First	United States
	Second	Denmark		Second	Austria
	Mean	0.4230		Mean	0.6976
15-16	First	United States	29-33	First	Finland
	Second	Netherlands		Second	United States
	Mean	0.6411		Mean	0.6699
17-19	First	United States	40-41	First	United States
	Second	Netherlands		Second	Netherlands
	Mean	0.7394		Mean	0.7052
20	First	United States	45	First	United States
	Second	Netherlands		Second	Finland
	Mean	0.7387		Mean	0.7669
21-22	First	United States	65-74	First	United States
	Second	Germany		Second	Sweden
	Mean	0.6969		Mean	0.7058
23-25	First	United States			
	Second	Netherlands			
	Mean	0.6666			

Table 1. Leaders in TFP and mean value in the respective industry. The identification code is taken from the OECD STAN and a detailed description is provided in the Appendix (section 6).

Moving the focus on ICT, a preliminary look at the data can suggest some of the results that will come from the regression. Figure 7 depicts the country-level change in ICT imports and the rate of growth of TFP that the industries of each countries experienced between 2000 and 2007. Three main features are easily spotted. First of all, the scatterplot displays a higher concentration of points at lower changes in ICT imports, meaning that few countries increased their imported stock of ICT at a yearly rate higher than 2.5%. Second, the trendline is almost flat, indicating the fact that no specific pattern seems to link the two factors. ICT imports and TFP growth appear to be uncorrelated regardless the , so neither those industries that benefitted from faster growth of technology imports appear to gain from it. This evidence supports the thesis of Griliches et al. on the insignificance of international trade. Finally, the data are characterised by a wide dispersions, so that it is reasonable to expect a large variance which consolidate the uncorrelated behaviour of ICT imports on TFP growth rate.

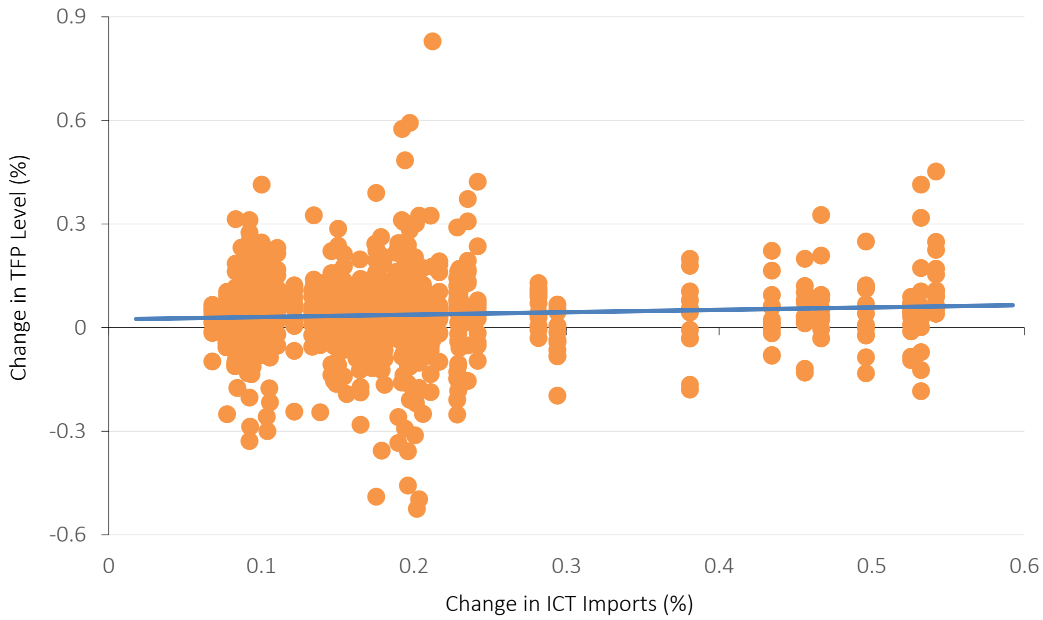

Figure 5. Change of ICT imports and TFP growth. Source: World Bank and author's calculations.

4. Results

The results from the regression are shown in table 3, where the estimated coefficients are written from column (1) to (5).

$\Delta lnTFP_{ijt}$		Observations = 923				
		(1)	(2)	(3)	(4)	(5)
$ln(R/Y)_{ijt-1}$	ρ_1	0.0074* (0.0043)	0.0112** (0.0046)	0.0104** (0.0045)	0.0041 (0.0077)	0.0103 (0.0079)
H_{it-1}	ρ_2	-0.0040*** (0.0014)	-0.0087*** (0.0021)	-0.0089*** (0.0021)	0.0030 (0.0067)	-0.0004 (0.0067)
$lnTFPGAP_{ijt-1}$	ρ_3	0.0476*** (0.0117)	-0.1608*** (0.0588)	-0.1683*** (0.0589)	-0.1883*** (0.0601)	-0.2155*** (0.0624)
$ln(R/Y)_{ijt-1} \times lnTFPGAP_{ijt-1}$	δ_1	-	-0.0136*** (0.0051)	-0.0139*** (0.0051)	-0.0140*** (0.0051)	-0.0159*** (0.0055)
$H_{it-1} \times lnTFPGAP_{ijt-1}$	δ_2	-	0.1362*** (0.0045)	0.0140*** (0.0045)	0.0123*** (0.0047)	0.0179*** (0.0047)
$ln\left(ICT_i^{IMP}/I_j\right)_{t-1}$	ρ_4	-	-	0.0113* (0.0067)	-0.0775* (0.0449)	-0.0908** (0.0451)
$ln(R/Y)_{ijt-1} \times ln\left(ICT_i^{IMP}/I_j\right)_{t-1}$	δ_3	-	-	-	-0.0031 (0.0031)	-0.0055* (0.0032)
$H_{it-1} \times ln\left(ICT_i^{IMP}/I_j\right)_{t-1}$	δ_4	-	-	-	0.0071* (0.0038)	0.0074* (0.0038)
$ln(ICT/I)_{ijt-1}$	ρ_5	-	-	-	-	0.0195* (0.0111)
$ln(R/Y)_{ijt-1} \times ln(ICT/I)_{ijt-1}$	δ_5	-	-	-	-	0.0027*** (0.0009)
$H_{it-1} \times ln(ICT/I)_{ijt-1}$	δ_6	-	-	-	-	-0.0011*** (0.0003)
Country fixed effects		Yes	Yes	Yes	Yes	Yes
Industry fixed effects		Yes	Yes	Yes	Yes	Yes
Time fixed effects		Yes	Yes	Yes	Yes	Yes

Table 2. Results from the regression estimating the effects of R&D, human capital, technology transfer, and ICT on the rate of growth of TFP. The different steps of the analysis are divided among columns (n), while the two kind of dataset are divided among columns [n]. Specifically, the dataset containing all the industries is employed in columns [1], whereas the dataset including only manufacturing industries falls under column [2]. The sample contains 1,041 observations for 13 industries of 10 OECD countries between 1995 and 2007. Due to missing values, the time frame is restricted of 5 years, from 2000 to 2007. Therefore, for columns [1] the number of observations reduces to 923, while for column [2] it goes down to 526. The asterisks indicate the level of significance of the coefficients. One asterisk (*) means a level of significance of 10%, or a p-value < 0.1, two asterisks (**) of 5%, or a p-value < 0.05, and three asterisks (***) of 1%, or a p-value < 0.01. The figure between parentheses represents the standard error of the estimation.

Column (1) shows the effect of R&D intensity, human capital stock, and technology transfer on the rate of change of TFP. All the coefficients enter significantly, although the R&D only at 10% level. This shows a positive correlation with ΔTFP, giving further evidence on the consolidated concept that R&D is a main source of productivity growth. The gap from the frontier exhibits a positive correlation too, supporting the idea that industries with lower technology level gains from technology transfer. Conversely, human capital shows a negative correlation with the change in TFP, although the elasticity is very low (not even close to 1%).

The following step takes into account the interactions between the technology transfer and the other two factors, the results are displayed in column (2). Once again, all the parameters enter significantly at 1% level and R&D acquires magnitude and significance. Contrasting the results from column (1), the technology frontier changes behaviour and shows a negative correlation with the change in TFP. Nevertheless, looking at the marginal effect that the frontier has on TFP growth, you find that the gap from the frontier exerts a positive impact on productivity, supporting the thesis of Griffith et al. (2004). In this way, industries that are lagging behind the technology frontier are able to acquire those spillovers on R&D activities and human capital. Indeed, considering the mean values of the latter elements, a 1% increase in the TFP gap of leads to a rise in productivity by 1.4%.

The analysis turns now to ICT, starting from column (3) where the parameter for ICT imports is added. The element enters positively correlated at 10% level. At this stage none real inference can be conducted to assess whether the nature of the source of ICT matters for the performance of TFP. Nevertheless, the result proves that ICT plays a positive role in the growth of TFP, that is industries which invest in this capital good experience higher rates of change of productivity. Whether the imports of ICT has any additional effect on productivity depends on the estimation that I get interacting it with R&D and human capital.

In column (4) I interact ICT imports with R&D and human capital. Interestingly, the results have the same pattern that you observe by adding of the interaction terms in column (2), despite the significance is much lower. The direct effect of ICT imports on TFP growth appears now negative, its joint effect with R&D has a negative correlation too (although it is not significant), and the interaction term with the human capital shows a positive coefficient with a significance at 10% level. Those correlations identify interesting relations between ICT imports, R&D activity, and human capital stock. Investments in foreign ICT and appears to have a substitution effect with expenditure in R&D, so that industries which do not invest in the creation of knowledge compensate this lack by acquiring ICT capital from abroad. In this way, productivity is promoted through investments in advanced ICT rather than R&D. The calculation of the marginal effect of ICT with respect to R&D makes clear this relation. Indeed, considering the industries below the 10^{th} percentile and above the 90^{th} percentile, you obtain very different results. An increase in ICT imports of 1% for those countries at the bottom of the investments in R&D, the increase in productivity reckons 3.8%. On the other side, the same increase for those countries at the highest level of R&D expenditure you observe an increase in productivity of 0.6% only. Therefore, there seems to be a trade-off between the expenditure in R&D and the need to acquire ICT from abroad. For what regards the marginal effect of ICT imports with respect to human capital, we have an opposite relation. Industries having a low stock of human capital perform poorer than those with a high amount do. This can be viewed as a specialisation undertaken by industries. Those that cannot rely on a high efficiency of their R&D activity, avoid to put effort on this field and they rather acquire better state-of-the-art ICT from abroad. In particular, it seems that a relevant stock of human capital is required in order to reap the benefits of investments from ICT imports. Indeed, for those countries lying below the 10^{th} percentile of human capital, a raise in imports of ICT capital by 1% leads to a decrease in TFP growth by 1%. Conversely, an increase of 1% in ICT imports by those countries lying on the mean or above the 90^{th} percentile causes the rate of growth of productivity to increase by 2% and 5% respectively. Thus, human capital appears like an element that is required to gain any benefits in productivity from importing ICT capital. To see whether those conclusions are solid, I need to inspect the effect that the control variables have on the parameters of ICT imports.

The control variables, which include the intensity of ICT investments and its interaction with R&D and human capital, are added in column (5). The share of ICT invested enters positive and significant at 10% level, proving the established fact that expenditure in this kind of capital promotes productivity growth. The interaction term between ICT investments and R&D enters positively into the regression and with a significance at 1% level. This gives further evidence to the mutual benefits that the two elements cause on each other, as supported by Corrado et al. (2014). Therefore, investments in either R&D or ICT give their best when they are done jointly, otherwise their impact in TFP growth is not as high as it could be. The statistical insignificance of R&D that arises in column (4) and (5), namely when its interaction with ICT entered into the analysis, is an additional insights towards this conclusion. Nevertheless, when the share of ICT investments is interacted with human capital, you have a negative correlation with the change in TFP. In section 2.3.1., I discussed some literature like Hall et al. (2010) and Melville et al. (2004) which finds an ambiguous link between ICT and human capital. This result is in line with their conclusions, which suggests that further research is required on this aspect. Nevertheless, the overall effect of ICT remains important for the growth of TFP. Taking into account all the interactions and the mean values for R&D and human capital, the results state that an increase in ICT investments of 1% raises productivity by almost 1.5%.

Besides those pleasant results on the direct effect of the control variables, their addition supplies important conclusion for the rest of the parameters. Not only all the previous results hold, but all the estimators gain in significance and show stronger effects. The imports of ICT maintain a negative and significant correlation with the rate of change of TFP, and same does the interaction term with R&D. Therefore, the trade-off arising from the acquisition of imported ICT or the investment in R&D is proved also by controlling for total ICT investments. Thus, the inferences previously drawn are still valid. In this case, considering the marginal effect of ICT imports with respect to R&D, an increase in the former by 1% causes boost in TFP growth by 3.7% for those industries with at the 10^{th} percentile of R&D investments. Instead, the ones that are on the 90^{th} experience, for the same increase in ICT imports, obtain a scant raise in TFP growth of 0.5%. For what regards the marginal effect of an increase in ICT imports by 1% with respect to human capital, industries having a stock of human capital at the 10^{th} percentile exhibit an decrease in TFP growth by 1.2%. On the other side, those being on the 90^{th} percentile experience a raise of almost 5%. Once again, it appears that a specialisation process is undertaken by industries that cannot rely on their R&D activity. Rather, they prefer to boost their productivity through the acquisition of state-of-the-art ICT.

The marginal effect of a 1% increase in ICT with respect to R&D or human capital are summarised in table 3.

Column	Marginal effect with respect to R&D		Marginal effect with respect to Human capital	
	10^{th} percentile	90^{th} percentile	10^{th} percentile	90^{th} percentile
(4)	3.8%	0.6%	-1%	5%
(5)	3.7%	0.5%	-1.2%	4.9%

Table 3. Marginal effect of an increase in ICT imports with respect to R&D and human capital. The variable which is not taken into the differentiation is considered a constant having the value of the coefficient of table 3 and the mean value of table 2.

5. Conclusions

The purpose of my thesis is to inspect the role that the acquisition of foreign ICT plays in the growth rate of TFP. For its particular features, ICT capital goods have multifaceted effects that range from direct to indirect ones. A clear understanding of those effects is necessary in order to explain trends in productivity that countries have experienced, and to provide recommendations regarding how to invest in ICT. A way to inspect the various channels through which ICT exerts its influence is to decompose it and to analyse the different parts that form it.

To fulfil this task, I choose to analyse the effect that the share of imported ICT on total investments has on TFP. With this measure, I aim to capture additional effects and relations that ICT imports may have on the rate of growth of TFP. In particular, from the study of this variable I aim to assess whether spillover effects arise and to draw some conclusions regarding the structure of the industries. Indeed, industries that acquire a large share of ICT imports may indicate that they channel their effort on different activities than R&D, another main source of productivity growth.

In order to have a complete analysis of the TFP's dynamics, I included in my model other elements like R&D, human capital, and technology transfer. The model is tested with an unbalanced panel data of 1040 observations for 13 industries of 10 OECD countries between 2000 and 2007.

The empirical test shows four main findings. First, a substitution effect seems to exist between the imports of ICT and the investments in R&D activity. Industries that spend little amount on the creation of knowledge experience the highest gains from ICT imports, while those investing very much on this activity cannot gain large benefits from imports in ICT. This indicates that industries undertake a specialisation process, so that expenditure on R&D activity is scant for those industries that cannot perform it efficiently. In ordero recover the missing productivity growth that R&D would ensures, those industries rely on ICT imports, allowing laggards in R&D to compensate for the growth in TFP.

Second, human capital plays an important role to acquire effectively foreign ICT capital. Industries endowed with a large stock of human capital can obtain a significant boost in TFP growth. This is consistent with the idea that, in the knowledge economy, a required amount of human capital is required so as to reap the benefits from state-of-the-art technology. The role of this particular kind of capital stock is so crucial that industries at the bottom cannot improve their productivity performance at all. On the other side, industries that can reckon on a high qualified workforce are able to obtain large benefits from the adoption of foreign ICT.

Third, when considering the link of R&D and the whole amount of ICT invested, the results show that investments in R&D make sense only when they are accompanied by the adoption of ICT capital. The failing of combining this two elements would not allow a complete exploit of the investments. This is corroborated by a significant strand of literature, like for instance the previously cited paper of Corrado et al. (2014).

Finally, the relationship between ICT and human capital remains blurred. As described in section 2.3.1., the positive correlation between those two elements may not be as obvious as one may think. Despite the results regarding the imports of ICT show a close link between the twos, this may not hold when considering the total equipment of ICT employed. Further research is addressed to this specific topic.

In conclusion, there are no doubts about the importance of ICT in boosting the growth of TFP. Nevertheless, the mechanisms by which it does so are complex and a clear understanding is has not be achieved yet. My thesis provides some insights about further channels of influence through which ICT may affect productivity. Those channels can be identified by a decomposition of ICT which has to take into account its most relevant parts. The results of my study show that the lack of R&D activity may be compensated by the import of ICT capital. This means that the production of domestic ICT may not be a necessary condition for raising the TFP. Specialisation of industries and countries may provide higher gains. Therefore, projects like the EU's Seventh Framework Programme aimed to reduce the productivity gap with the U.S. should focus on the acquisition of ICT only, rather than the creation of an ICT producing and research industry. Indeed, the forced creation of an industry that performs R&D on ICT and that manufactures it may allocate resources inefficiently. Letting industries to specialise on those activities for which they can produce in the most efficient way would promote the growth rate of TFP in a better way.

Appendix

Descriptive tables.

Industry code	Description	Industry code	Description
01-05	Agriculture, forestry and fishing	26	Other non-metallic minerals
10-14	Mining and quarrying	27-28	Basic metals and fabricated metals
15-16	Food products, beverages and tobacco	29-33	Machineries and equipment
17-19	Textiles, wearing apparel, leather and footwear	40-41	Electricity, gas and water supply, sewerage and waste management
20	Wood and products of wood and cork	45	Construction
21-22	Paper, paper products and printing	65-74	Financial, insurance and real estate activities
23-25	Chemical, rubber, plastics and fuel products		

Table 5. Description of the industry code. Source: OECD STAN.

Variable	Description	10^{th}	Sample mean	90^{th}	Source
ΔlnA_{ijt}	Logarithmic change in total factor productivity from *t-1* to *t* for industry *j* of country *i*. It is the dependent variable of the model and it measures the percentage change in the level of TFP. A positive sample mean signifies that the average value in my dataset corresponds to a positive TFP growth slightly higher than 1%.	-0.0712	0.0364	0.1446	Author's calculations
$ln\left(\frac{R}{Y}\right)_{ijt-1}$	Logarithmic value of the R&D intensity for industry *j* of country *i*, lagged by 1 period. It is given by the ratio between the expenditure on R&D activities and the value added of the industry. The logarithmic transformation allows you to determine the effect of a change in 1% of R&D intensity to the percentage change in TFP growth.	-8.240	-5.060	-2.485	OECD STAN
H_{it-1}	Percentage of the population over 25 years old that completed the tertiary level of education in country *i*, lagged by 1 period. It is used as a proxy for human capital and it gives us the effect on the percentage change in TFP growth caused by a 1% change in the educational level of the above-mentioned population.	6.8	11.12	15.11	Barro and Lee

$ln\left(\frac{A_F}{A_{ij}}\right)_{t-1}$	Logarithmic value of the gap in TFP from the frontier for industry *j* of country *i*, lagged by 1 period. It is determined by the ratio between the TFP level of the frontier and the TFP level of the non-frontier industry. The logarithmic transformation allows you to determine the effect of a change in 1% of TFP gap to the percentage change in TFP growth. It is used as a proxy for the technology transfer.	0.009 5	0.4623	0.8138	Author's calculations
$ln\left(\frac{ICT^{IMP}{}_i}{I_j}\right)_{t-1}$	Logarithmic value of the share of ICT imports of country *i* on the total investments for industry *j* of the same country, lagged by 1 period. It includes all the goods related to ICT, and specifically: telecommunications, audio and video, computer and related equipment; electronic components; and other information and communication technology goods. Software is not taken into account. The logarithmic transformation allows you to determine the effect of a change in 1% in the amount of ICT imported to the percentage change in TFP growth. The negative value indicates that the amount of ICT imports is smaller than the sectorial investment spending.	-2.441	-1.809	-.09655	World Bank and OECD STAN

Table 5. Description of the regressors. Source: OECD STAN, World Bank Database.

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