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Technical change and growth in an economic complexity perspective

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Resumo

Desenvolvimento e crescimento econômico pressupõem transformação estrutural e mudança tecnológica. Esse processo envolve subir a escada tecnológica e mover-se em direção a atividades de maior produtividade, adquirindo conhecimentos e *capabilities*. Recentemente, novas evidências empíricas mostraram que países tendem a seguir trajetórias de mudança tecnológica coerentes, gradativamente incorporando produtos mais complexos. Estes reuniriam mais conhecimento e estariam associados a uma melhor performance econômica. Diversos estudos têm investigado a importância da sofisticação econômica e de produto para o comércio, o crescimento da produtividade e o crescimento da renda. O presente estudo se dedica a analisar a questão do desenvolvimento econômico à luz das contribuições empíricas fornecidas pela abordagem da complexidade. Contudo, embora tais trabalhos forneçam ricas evidências de que aquilo que um país produz importa para o seu desempenho econômico, eles carecem de uma base teórica bem fundamentada para interpretação de seus resultados. Diante disso, sugere-se analisar tais evidências com base na literatura Schumpeteriana, a qual incorpora as externalidades provenientes dos processes de aprendizagem e o processo de mudança estrutural ao explicar aumentos de produtividade e crescimento econômico. De acordo com esse arcabouço, os mecanismos que promovem a mudança estrutural apontam principalmente para os esforços em gerar conhecimento e para a capacidade de absorver tecnologias produzidas pela fronteira com vistas a reduzir os diferenciais de produtividade. De fato a noção de sofisticação está interligada ao conteúdo tecnológico embarcado nos produtos e regressões em painel mostraram que a intensidade de pesquisa impacta positivamente os níveis de sofisticação econômica. Além disso, esta dissertação também provê evidências de que a estrutura positiva dos países impacta a sua habilidade de reduzir o hiato tecnológico em relação à fronteira. Regressões em painel mostram que países que produzem produtos pertencentes a indústrias mais sofisticadas têm maior potencial de absorver tecnologia da fronteira. Esses resultados apontam para a importância dos esforços destinados a orientar a composição produtiva de um país em direção a bens de maior complexidade e maior conhecimento embarcado, bem como de explorar seu potencial de incorporação de novas tecnologias de modo a promover um caminho virtuoso de desenvolvimento.

Palavras-chave: Sofisticação Econômica; intensidade de pesquisa; *gap* tecnológico.

Abstract

Development and growth presuppose structural transformation and technological change. This process involves climbing the technological ladder and moving towards activities of higher productivity by acquiring more complex sets of knowledge and capabilities. More recently, new empirical evidence have showed that countries tend to follow coherent paths of technological change by moving towards more complex goods. These would be the ones that incorporate higher knowledge and are associated with better economic performance. A number of works have been investigating the importance of product and economic sophistication for trade, productivity growth and income growth. The present work aims to address the issue of economic development and structural change in the light of the empirical contributions provided by the economic complexity approach. Although these works provide prolific empirical evidence that what a country produces matter to its economic performance, they lack a theoretical basis to assess and interpret such results. Hence, some of the insights provided by its empirics are analyzed in the light of the Schumpeterian literature, which incorporates learning externalities and structural change in explaining productivity increases and economic growth. Within this framework, the mechanisms that promote structural change mainly point to the efforts in generating higher knowledge and the ability to absorb technology produced by frontier countries as means to close the productivity gap. Indeed sophistication has something to do with technology and panel regressions have showed that research intensity positively impact economic sophistication. Moreover, this dissertation also provides evidence that a country's productive structure impacts its ability to close the technology gap relative to frontier countries. Panel regressions showed that countries producing goods in the more sophisticated industries enjoy higher potential to absorb technology from the technological frontier. These results point to the importance of efforts in orienting the composition of production towards higher complexity and higher knowledge products, as well as exploring its potential in incorporating higher technology, allowing for a virtuous path of development.

Keywords: Economic sophistication; research intensity; technology gap; absorptive capacity.

List of Figures

List of Tables

Contents

Introduction

A wide literature acknowledges that development and growth presuppose structural transformation and technological change (e.g. Lewis (1958), Rostow (1958), Kaldor (1966), Prebisch (1962) and Furtado (1964)). In this process, production shifts towards activities of higher productivity and value added by gradually acquiring more complex sets of knowledge and capabilities necessary to promote technical change. As a result, an economy's overall productivity increases, closing the technology gap relative to frontier countries (ABRAMOVITZ, 1986).

More recently, studies revived these ideas by introducing new methodologies for the empirical analysis of economic development. According to the so-called "Economic Complexity Approach", well-performing countries are found to be the ones that have productive structures oriented towards the production of more sophisticated goods (HIDALGO et al., 2007; HIDALGO; HAUSMANN, 2009; HAUSMANN et al., 2011). This perspective does not claim any novelty in the idea that what a country produces have different consequences for development, but rather suggests news ways of assessing products characteristics and ranking them according to their implicit nature (HIDALGO et al., 2007; HAUSMANN; HWANG; RODRIK, 2007; HAUSMANN et al., 2011). The characteristics inherent to each product are captured by measures based on their associated productivity levels (HAUSMANN; HWANG; RODRIK, 2007), on the relatedness and flexibility of the associated knowledge (HIDALGO et al., 2007) and the diversification and uniqueness of each one of them (HIDALGO; HAUSMANN, 2009). Countries, on their hand, are regarded through the sophistication (or complexity) of the products that compose their specialization patterns, showing that what a country produces matter for its subsequent economic performance.

This approach is consistent with the idea that development follows a path dependent and cumulative process that involves learning efforts and knowledge accumulation. Moreover, it stresses that not all products have the same consequences on development, being compatible with the argument that development involves climbing the technological leader and engaging in the production of new more knowledge intensive goods. As a consequence, this approach also agrees with the notion that the forces of comparative advantage lay more heavily on a country's capabilities to master, use and produce technologies than on factor endowments. Lastly, it is coherent with perspectives emphasizing the importance of technical change to long run growth.

In fact, the new empirical evidence resulting from product and country sophistication measures restored the debate on the importance of structural change for long term performance. Following these ideas, a number of works have been investigating the importance of product and economic sophistication for trade, productivity and income growth (e.g. Felipe et al., 2012, Hartmann et al., 2017, Romero & Britto, 2018). A series of authors have also incorporated its empirics in studies based on relatedness perspectives (BOSCHMA; IAMMARINO, 2009; NEFFKE; HENNING; BOSCHMA, 2011; BOSCHMA; BALLAND; KOGLER, 2014), regarding the Latin-American structuralist tradition (GALA; CAMARGO; FREITAS, 2017), as well in combination with some Schumpeterian insights on capability building (PETRALIA; BALLAND; MORRISON, 2017).

Nonetheless, although sophistication measures are found to provide strong empirical support to visions on the importance of the productive structure and its consequences in terms of development, the authors within this approach do not regard the process underlying sophistication increases. Sophistication is regarded as a reflection of the capabilities embedded in products and specialization patterns. However, the processes by which countries learn and acquire capabilities, lacks explaining. Once sophistication exerts an important impact on growth and development, it is central to understand the means by which a country accumulates capabilities

As means to address this questions, this dissertation appeals to Schumpeterian insights concerning knowledge accumulation and technological absorption. In this vein, two central ideas regarding the process of generating technical change are transposed to the sophistication empirics. Firstly, the importance of technological transfer is emphasised. According to the technology gap theorists, productivity differences across countries opens up opportunities for technological transfer, allowing for backward economies to catch-up by imitating technology from the frontier (POSNER, 1961; ABRAMOVITZ, 1986). Some factors are found to reinforce this process, such as research intensity efforts and human capital (GRIFFITH; REDDING; REENEN, 2004). This leads to the second core insight os Schumpeterian growth models, namely the importance of national technological activity. The economies' efforts in promoting technical progress are at the core of Schumpeterian growth model, which incorporate learning by doing and technical change in explaining output and productivity growth.

The first chapter reviews the classical theories of development and point to the mechanisms that would promote structural change. It is argued that much of this literature appeals to the empirics built by the complexity approach in supporting much of the formers ideas. This chapter also present the more recent works regarding the complexity approach, laying out the more relevant questions raised so far in the literature regarding its empirical findings.

The main Schumpeterian insights related to the process of technological change are presented in chapter 2. This perspective is consistent with the view that development is a cumulative and path dependent, emphasizing learning and capabilities accumulation as means to promote structural change. This process are conceived at the micro level, concerning the abilities of firms to absorb technology and innovate, with important consequences for economic growth. This ideas, in turn, are transpose to a macro level concerning technological transfer and national technological activities. At both the micro and the macro levels, Schumpeterian works provide vast empirical works in support of its ideas.

Chapter 3 investigates the impact of a country's composition of production on absorptive capacity and its influence in closing the gap relative to countries in the technological frontier. The concept of absorption capacity defined by Cohen & Levinthal (1990) refers to the ability of recognizing the value of new information, to assimilate it and exploit it commercially. These ideas are combined with the notion of industry sophistication based on the works of Hausmann, Hwang & Rodrik (2007) within a technology-gap framework. It assumes that what a country produces, measured by the index of industry sophistication, would have an important impact on absorptive capacity by increasing a country's potential to absorb technology from the technological frontier. This is tested for a sample of eleven OECD countries and 11 manufacturing industry in a 27-year panel.

Lastly, chapter 4 aims to assess the determinants of economic sophistication by adopting as reference a theoretical framework compatible with learning externalities and structural change. To investigate the main determinants of economic sophistication (EXPY), as measured by Hausmann, Hwang & Rodrik (2007), Schumpeterian insights concerning national technological activities. Panel regressions on a sample of developing and developed countries over 15 years are employed to asses Hausmann, Hwang & Rodrik's (2007) prior investigation on the covariates of EXPY. The results are interpreted in light of the mechanisms that foster endogenous technological progress by incorporating research intensity in the determination of economic sophistication, shedding light to the supply-efforts in building technological capacity impacting on economic sophistication.

1 Technical change and economic complexity

1.1 Introduction

Development has been discussed as a process of structural transformation since the 1950s and 1960s, when the classical theories of economic development described it as a process in which resources were transferred from activities of lower productivity into activities of higher productivity. These shifts, whereby developing countries increase the participation of the industrial sectors in total output, would allow for increasing returns and overall productivity growth, creating a sustained development path and long run economic growth (LEWIS, 1958; ROSENSTEIN-RODAN, 1958; NURKSE, 1958; KALDOR, 1966).

Technology-gap theorists (e.g. Posner, 1961, Gerschenkron, 1962 and Abramovitz, 1986), in turn, regarded development as a process of closing the technology gap, which is expressed in productivity differences across countries. To close that gap, developing economies should climb the technological ladder based on technology transfer and R&D efforts oriented to creating innovations and absorbing new knowledge and new technologies created abroad.

From an innovation perspective, knowledge is eminently tacit and dependent of trajectory, so that to move towards new activities associated with higher productivity is necessary to acquire more complex sets of knowledge and capabilities, promoting local learning processes. Increased technological progress would then lead to productivity increases, higher income elasticities of demand and returns to scale, creating externalities and reinforcing learning processes.

More recently, the works of Hausmann, Hwang & Rodrik (2007), Hidalgo et al. (2007), Hidalgo & Hausmann (2009) and Hausmann et al. (2011) presented new empirical evidence in line with these ideas, by introducing a series of outcome-based measures that aim to asses the importance of the composition of production and trade to economic performance. These works have shown that well-performing economies tend to have productive structures oriented towards the production of more sophisticated goods, highlighting the importance of the type of goods being exported for self-sustaining growth (HAUSMANN; HWANG; RODRIK, 2007; HIDALGO et al., 2007; HIDALGO; HAUSMANN, 2009; HAUSMANN et al., 2011; FELIPE et al., 2012).

Still, the empirics provided by this approach can be interpreted from different perspectives. For instance, they have been explained from a relatedness perspective (e.g. Boschma, Balland & Kogler, 2014), from a Latin American structuralist perspective (e.g. Gala, Camargo & Freitas, 2017) or either from the classical theories of development (e.g. Felipe et al., 2012). Such empirical findings remain a field of research open to different interpretations on the determinants of complexity and the mechanisms working behind the results found by this literature.

The present chapter aims at discussing how development theory addressed the composition of production in generating economic growth, since its early classical theories of the 1950s and 1960s. Approaches to economic growth compatible with the notion of technical change, learning and knowledge spill-overs are also incorporated to help providing a background for introducing the economic complexity approach. The following section focuses on the classical theories of development. Next, growth theories approaching the importance of demand and supply for structural change are discussed. Lastly, the economic complexity approach is presented.

1.2 Classical theories of development

The classical literature from the 1950s and 1960s regard economic development as a process of structural transformation, in which developing economies transfer resources from low to high productivity activities and incorporate new dynamic sectors of higher value-added (ROSENSTEIN-RODAN, 1958; NURKSE, 1958; LEWIS, 1958; HIRSCHMAN, 1958; KUZNETS, 1958). This, in turn, are opposed to low-value added sectors such as agriculture, mining or other informal activities typical of underdeveloped economies. In this context, industrialization is acknowledged as the main way out of the underdeveloped condition, being the manufacturing sector the one with higher increasing returns, higher incidence of innovations, more linkages, higher externalities and higher opportunities for technical change.

Lewis (1958) put this in terms of a dual economy, in which a modern sector develops alongside subsistence (or informal) activities. In this setting, new dynamic sectors could draw upon the labour surplus available in the backward areas as means to fulfill its labour requirements. Transferring workers from backwards to dynamic activities, consequently would increase overall labour productivity and provide better payments. For Lewis (1958), the growth of productivity would be determined by the relative growth of the higher productivity sector.

Nonetheless, to sustain this process, new industries and new knowledge has to be continually created and economies should constantly diversify towards more dynamic sectors with higher growth of demand and also potential for technical change. The diversification of the productive structure, the expansion of the technological content and the dynamism of demand would allow for the growth of productivity to be accompanied by the growth of employment in the modern sectors. Without the transformation of the production structure through the creation of new sectors and technological upgrading, it would not be possible to transfer labour from subsistence segments towards higher-productivity activities (LEWIS, 1958).

Considering that underdeveloped countries lack capital intensive sectors and a structured industry, different strategies for fostering the industrialization process have been suggested. The pioneers of development agreed on the need for building a manufacturing sector through a development plan, emphasizing the role of the government in conducting this process. Nonetheless, the strategies concerning the means to generate and explore the externalities necessary for this process differed.

On the one hand, the "balanced growth theory" (e.g. Rosenstein-Rodan, 1958 and Nurkse, 1958) argue in favor of large scale and somewhat synchronized investments oriented to boost industrialization, as means to benefit from dynamic externalities, increasing returns and demand complementarities supporting the process of development. Most importantly, the complementarities between various sectors should be explored, so that they could provide support for each other through coordinated efforts along the development process. Because of it, such development program should supposedly be conducted by the State to guarantee the best investments to the economy as whole, covering the grounds that would not be contemplated by market mechanisms alone.

In contrast to these strategies, the "unbalanced growth theories" (e.g. Hirschman, 1958 and Myrdal, 1957) acknowledged that the conditions for development would be created by perpetrating imbalances across sectors. According to Hirschman (1958), backward and forward linkages in production would generate externalities and induce investments by creating demand for intermediate inputs, raw materials and innovations. Such linkage effects between different sectors would provide the mechanisms needed for simultaneous and progressive expansion in domestic demand and supply. Particularly, the manufacturing industry of intermediary products and consumer goods would be able to provide the strongest linkage effects, engendering higher economies of scale and positively affecting overall productivity.

In similar lines, Myrdal (1957) also addressed the process of development as a series of imbalances. His theory of development emphasised circular cumulative causation mechanisms that could influence positively or negatively the economy. The author also emphasised that institutional and political structures – referred to as "non-economic factors" – also operated in the development process and played a crucial role, since free market forces alone would generally tend to increase development disparities.

Accordingly, the understanding that industrialization can promote growth through cumulative causation mechanisms can be found in the demand-led Kaldorian models operating through the Verdoorn Law. According to it, the growth of labour productivity is likely to be faster when the growth of output accelerates. This could be explained through the transference of workers from low-productive sectors to modern sectors, as well as by the presence of static and dynamic increasing returns to scale stemming from positive externalities, technological spillovers and learning by doing (KALDOR, 1966).

In the light of the obstacles for development in Latin America, a body of literature emerged regarding the causes of underdevelopment in the region. The Latin American structuralist tradition points to two fundamental features of underdeveloped economies, namely its specialized character and its heterogeneous structure. In its interpretation, the productive structure plays an important role in setting the possibilities and constraints for development. According to it, the concentration of technical change in a few activities would set the specialized character of underdeveloped economies. As a result, underemployment would persist in the subsistence sectors while modern sectors would be able to absorb only part of the labour surplus (RODRIGUEZ, 2009).

In this lines, structural heterogeneity is defined as the coexistence of high and low-productivity sectors. While the former concerns the export-oriented agricultural sector and some industrial activities, the latter usually concerns the ones that employ technologies that result in significant lower productivity. Such activities are typically characterized by weak increasing returns and little effect on both demand growth and structural change. Moreover, the technological dynamics in peripheral countries reinforces its specialized character, in that the lack of complementarities between sectors hampers the technology diffusion across different activities(RODRIGUEZ, 2009).

It is argued that in developing countries technology is not evenly diffused across sectors, whereas in developed economies it spreads relatively fast to the entire productive structure. Moreover, how technology is diffused in the world economy is argued to define a center and a periphery. The former refers to countries where the capitalist means of production are firstly incorporated. In contrast, the latter concerns the relatively backward economies in which technology only achieves a few limited exporting sectors oriented to the industrial core (RODRIGUEZ, 2009).

According to Furtado (1964), economic development rests upon the diffusion and incorporation of technological progress and the consequent increases in productivity. While growth in the center is driven by the incorporation and spread of new techniques across all sectors, the periphery continues to rely on technology imports, mainly directed to primary exports sectors. This would perpetrate the existence of low-productivity sectors with labour surplus and low wages, deepening the asymmetries between development and underdevelopment.

The natural way out of the peripheral condition would once again be industrialization. It is argued that a shift to manufacturing activities would promote aggregate productivity increases and stimulate technological diffusion, as well as increase wages. Nonetheless, the primary-exporting condition of peripheral economies and its pattern of technological creation and diffusion reinforce its specialized character and obstruct industrialization. The lack of complementarities between sectors and incipient vertical integration could hinder this process.

On these grounds, Fajnzylber (1990) argued that it would not be possible to overcome underdevelopment without the creation of an "endogenous nucleus of technological dynamism". Its creation, in turn, would depend on policies that promote the development of the capital goods sector. This is the sector that incorporates higher technological progress, as well as allows a reduction of the structural deficit in the current account. Regarding the Latin America experience, the author argued that the region's productive structure is based on foreign technologies, transferred from transnational companies based in developed countries. Therefore, policies should focus not only on debt reduction, but also on inducing the innovative behavior domestically, contributing to the expansion of the technological frontier.

Nonetheless, establishing such dynamic technological processes in developing economies would not be possible without major structural changes and the implementation of a manufacturing sector. That is where higher increasing returns can be found, generating externalities and technological learning to create indigenous skills in core technologies. Developing such sectors would be virtually the only way for draining the labour surplus from low to high-productivity activities. Hence, an industrialization process based on increasing production sophistication is seen as the path for development and catching-up of underdeveloped economies.

In order to foster the expansion of productivity, employment, and output, technological upgrading should come along the transformation of the production structure. Whilst the structuralist theory turned to the relationship between structural change and development, the Schumpeterian approach concentrated on the processes at the root of structural transformations. More specifically, it turned to the processes by which knowledge is accumulated, leading to the idea that a series of efforts directed towards learning impact technological progress. These refer to the supply side of technological change, which will be discussed in the following section.

1.3 Economic complexity approach

In a series of works, Hausmann, Hwang & Rodrik (2007), Hidalgo et al. (2007), Hidalgo & Hausmann (2009) and Hausmann et al. (2011) presented new analytical tools to measure the sophistication of a country's productive structure. These provided important empirical contributions in characterizing products and countries in terms of their implied sophistication (or complexity). These measures rest on the premises that what an economy produces reflects the knowledge embedded in the society.

Crucial to the authors' approach is the evidence that not all products carry the same consequences for development, in that products would differ in terms of the spillover effects that stem from production. Precisely the ones that embody higher knowledge would have higher spillover effects that ease the transformation of the productive structure, by enabling the relocation of productive resources into producing new goods.

According to this approach, development is regarded a process of learning how to produce new and more complex goods, meaning not only improving upon the production of the same goods, but also accumulating more complex sets of knowledge and skills necessary to move towards activities associated with higher levels of productivity. Countries, however, would differ in their development paths according to the capacity to accumulate and put into use different sets of knowledge.

The results presented by Hidalgo & Hausmann (2009) suggest that shifts in a country's productive structure can be regarded as a combination of two processes. The first one consist on the process by which countries move to new products that are recombinations of previous capabilities. The other one refers to the process of developing more products by accumulating new capabilities and combining them with the ones previously available.

Since the amount of knowledge an economy has resides on its productive diversity and on the learning processes that follow production experience, more important than continuously improving upon the production of the same goods is focusing on the increases in productivity that arises from shifting to new products. On these grounds, the complexity of a product is defined as a function of the capabilities it requires, whilst the complexity of a country is given by the number of locally available capabilities.

The works within this approach are presented in three subsections. The first presents the notions of country ad product sophistication (or complexity), while the second turns to the product space model. The last summarize the recent developments produced within this framework.

1.3.1 Product and economic sophistication

The empirical evidence offered by the work within the economic complexity approach is interpreted in terms of that economic sophistication reflected in the composition of a country's productive output. This, in turn would be a reflection of the amount of productive knowledge an economy contains. The main novelty is defining outcome-based measures for ranking products. The notion of country sophistication assesses the ability to export products produced by rich countries, considering that, overall, they embody higher productivity, wages and income per capita (HAUSMANN; HWANG; RODRIK, 2007).

Initially, the method suggested by Hausmann, Hwang & Rodrik (2007) aimed at measuring product and country sophistication in two steps. Firstly, each good is associated with a productivity level through an index named PRODY, obtained as the weighted average of per capita GDP of its exporters:

$$PRODY_i = \sum_c \left[\frac{\left(\frac{x_{ci}}{\sum_i x_{ci}} \right)}{\sum_c \left(\frac{x_{ci}}{\sum_i x_{ci}} \right)} \right] Y_c \tag{1.1}$$

where x denotes the exports of the product i by the country c and Y is its income per capita.

The resulting index ranks the traded goods in terms of the average income level of the countries exporting them. Therefore, it basically informs that if a product is produced by a high income country it is sophisticated.

Next, a country's sophistication index is measured based on the productivity level associated with a country's export basket. The referred index is named EXPY and is obtained by the weighted average of PRODY, in which the weight corresponds to the relative share of a product in the total exports. Algebraically, EXPY is defined as:

$$EXPY_c = \sum_i \left(\frac{x_{ci}}{\sum_i x_{ci}} \right) PRODY_i \tag{1.2}$$

Both indexes, PRODY and EXPY, are not free of criticism. The PRODY of some products is counterintuitively high and when product quality is not taken into account, EXPY overestimates the importance of sophisticated products from low-income countries (REIS; FAROLE, 2012)[1]. It should also be noted that since PRODY is held fixed across countries, differences in sophistication are only due to differences in export composition and do not reflect differences in quality within a product category. This is an important limitation, since the quality of products in a same category may vary significantly across countries[2].

Despite that, Hausmann, Hwang & Rodrik (2007) have shown that EXPY is a good predictor of future growth. It enters most strongly in countries at intermediate income levels and is found to be higher than income per capita in fast growing countries. This would indicate that such economies are producing goods associated with higher income levels. Although economic sophistication and income are partly related by construction, the authors claim that this relationship is not merely a mechanic one.

The problem, however is that since PRODY and EXPY are measures built upon information on both income data and on the structure of the network, they would imply a circular conclusion that "rich countries export rich countries goods" (HIDALGO et al., 2009). Hence, to improve this indicators, Hidalgo & Hausmann (2009) suggested isolating the network effects according to what they called the "Method of Reflections". In that case, instead of using income information, the authors suggest an iterative method that characterizes simultaneously countries and products relative to each other.

The starting point is the construction of a matrix M_{ci} that describes the bipartite network of countries and products. In the construction of the matrix M_{ci} the rows contemplate countries and the columns represent products. If a country c has $RCA_{ci} \geq 1$ in a product i it is represented in M_{ci} by 1 and zero otherwise[3].

It follows that two measures are defined: diversification and ubiquity. The sum of the

[1] This has led authors like Lederman & Maloney (2012) to conclude that *how* a country produces an export matters more than *what* it produces.

[2] In regard to this matter, Romero (2015) argued that productivity still is a better proxy for product quality than the EXPY.

[3] When rearranging the various rows and columns of M_{ci} we should observe an approximately triangular matrix. This suggests that countries tend to produce all possible goods given their technological capabilities level, indicating that competitive gains might come from diversification rather than specialization. Whilst developed countries have diversified export baskets, less developed countries export fewer, lower complexity products (TACCHELLA et al., 2012).

rows results in a measure of a countries' diversification denoted by $k_{c,0}$, which corresponds to the number of products that constitute its export basket:

$$k_{c0} = \sum_{i=1}^{N_i} M_{ci} \tag{1.3}$$

The sum of the columns results in a measure of products' diversification denoted by $k_{i,0}$, which corresponds to the number of countries exporting a given product

$$k_{i0} = \sum_{c=1}^{N_c} M_{ci} \tag{1.4}$$

The method of reflections consists in calculating interactively the average values of the previous measures of diversification and ubiquity. These, therefore are defined simultaneously and at each iteration more information is added:

$$k_{cN} = \frac{1}{k_{c0}} \sum_{i} M_{ci} k_{iN-1} \tag{1.5}$$

$$k_{iN} = \frac{1}{k_{i0}} \sum_{c} M_{ci} k_{iN-1} \tag{1.6}$$

where N is the number of iterations, being $N \geq 1$.

These complexity measures should be interpreted in terms of the resulting average from their interaction. Countries are characterized by the vector $\vec{k_c} = (k_{c0}, k_{c1}, \ldots, k_{cN})$ and products are characterized by the vector $\vec{k_i} = (k_{i0}, k_{i1}, \ldots, k_{iN})$. For countries, even variables are generalized measures of diversification $(k_{c0}, k_{c2}, k_{c4} \ldots)$ while odd variables are generalized measures of ubiquity $(k_{c1}, k_{c3}, k_{c5} \ldots)$. The inverse is valid for products.

It is verified that more diversified countries are able to produce less ubiquitous products, represented by a negative relationship between this two measures. It is also argued that because more diversified countries can produce a wider set of products – including those that require many capabilities – they are able to produce less ubiquitous goods (HIDALGO; HAUSMANN, 2009).

Additionally, as shown by Hidalgo & Hausmann (2009), both diversification and ubiquity measures are found to be correlated with income and as they are iterated the correlation increases. Moreover, the method is accurate to control for the size of a country's population as well as outperforms other usual measures of diversification such as the Hirschman-Herfindahl index and entropy measures.

Equation 1.5 and Equation 1.6 are iterated until the resulting relative rankings of products and countries remain unchanged, that is, the nth iteration is the same as $n + 1$. It means that no further information can be added by any additional iterations. This method result in the economic complexity index (ECI), which proxy for the locally available capabilities in a country, and the product complexity index (PCI), which accounts for the capabilities required by a product. Countries that score high in ECI are those with a large and diversified set of capabilities, whilst products that score high in PCI are the ones that require many capabilities (HAUSMANN et al., 2011).

Product complexity is interpreted as the number of capabilities required for production, while economic complexity is seen as a reflection of the amount of capabilities available in the country. As an evidence of this, Hidalgo & Hausmann (2009) show that the number of employment categories that goes into the export basket of countries is strongly and positively correlated with the measures of diversification. The inverse relationship is found for the ubiquity measures, endorsing the idea that more diversified countries produce more complex products, considering that they require a wider set of capabilities.

Finally, the matrix M_{ci} exhibits strong path dependency, regarding the fact that as capabilities are accumulated, they might be recombined to create new products of higher complexity. A country's productivity resides in the diversity of its available nontradable capabilities and, therefore cross-country differences in income would be explained by differences in economic complexity (HIDALGO; HAUSMANN, 2009).

1.3.2 The product space model

On its hand, Hidalgo et al. (2007) introduced the "product space", which provides a visualization of all products exported in the world linked by the probability of their co-exportation. The authors explain the product space model through a simple analogy between monkeys and trees. In that case, a tree represents a product while the forest is a set of all products. Taking monkeys as firms, shifts in the production composition of a country, should occur when they jump from poorer parts of the forest to richer parts. However, if monkeys can jump only limited distances and the forest has both dense parts and sparse areas, they would only be able to jump if the trees are close to each other.

These jumps are translated into recombining capabilities (human and physical capital, for example) towards goods there are different to the ones currently produced. The probability of firms jumping from one product to the other would depend on how far firms currently find themselves in terms of the knowledge and skills necessary to perform such activities. Proximity between products might ensue from physical factors (labour, land and capital), the level of technological sophistication, or similar requisite institutions and infrastructure (HIDALGO et al., 2007).

Still, instead of defining a priori the sources of relatedness between products, Hidalgo et al. (2007) suggested using outcome-based measures based solely assuming that if two goods share a common set of inputs and capabilities they will tend to be produced together. The product space is thens built upon international trade data using network analysis methods to provide an outcome-based measure to assess the relatedness between products.

First of all, to identify the products that matter in characterizing a country exports, Hidalgo et al. (2007) utilize the index of revealed comparative advantage (RCA) as defined by Balassa (1965). It corresponds to the ratio between the share of exports of the sector i in the country c and the share of c in the world's exports:

$$RCA_{ci} = \frac{x_{ci} / \sum_i x_{ci}}{\sum_c x_{ci} / \sum_i \sum_c x_{ci}} \tag{1.7}$$

If $RCA_{ci} \geq 1$ it is considered that a country c has RCA in a product i[4].

Based on this, the product space is built by mapping the probabilities of jointly exporting a pair of products with RCA. The measure of "proximity" formalizes the notion that if a country has RCA in the production of a certain good, it will most likely be able to also achieve RCA in a new similar good by recombining inputs and capabilities.

Formally, the probability of jointly exporting a pair of products is defined by the minimum pairwise conditional probabilities of exporting a certain product i given it already produces the product j:

$$\varphi_{ij} = \min \left\{ P\left(x_i \mid x_j\right), P\left(x_j \mid x_i\right) \right\} \tag{1.8}$$

where $x_i = 1$ if $RCA > 1$ and 0 otherwise.

The pairwise distances of all products are represented in a proximity matrix. As pointed by Hausmann & Klinger (2006) the foundational models of growth and trade have some implications for the shape of this matrix. In the Hecksher-Ohlin model productive opportunities are determined by relative factor endowments, resulting in a block-diagonal matrix in which countries could only jump to products that require factors available with relative abundance. On the other hand, quality-ladder models imply that new products at reach are slightly more complex than the previous ones, requiring some adaptations or R&D efforts (GROSSMAN; HELPMAN, 1991; AGHION; HOWITT, 1992). Still, they implicitly assume that the distance between the current products and new products does not vary, implying in a perfectly homogeneous product space Hausmann & Klinger (2007).

The proximity matrix built by Hidalgo et al. (2007), however is far from homogeneous and appears to have a core-periphery structure in which a number of goods are highly connected in the core and many others only sparsely connected in the periphery. As revealed by the network

[4] Different cutoff points in defining a country RCA has been tested and 1 have proven to be robust (HIDALGO et al., 2007; FELIPE et al., 2012).

representation of the matrix, the core encompasses especially metal products, machinery and chemicals whereas the periphery is constituted mostly by fishing and agriculture.

Based on the structure of the product space, the authors explore how the set of products that a country exports may have important consequences for the pattern of development. The authors point that comparative advantage diffuses preferentially toward products close to existing goods, therefore the lack of connectedness could be an explaining factor for the difficulties faced by countries in promoting structural change. A highly connected product space could ease the problem of growing the complexity, while a sparsely connected product space would make it harder. (HIDALGO et al., 2007; HAUSMANN et al., 2011).

Lack of connectedness between products in the periphery (low-productivity products) and in the core (high-productivity products) would explain the difficulties developing countries face converging to the rich countries' income levels. If the product space is disconnected, countries will not be able to find paths to the richer parts of the product space, independently of how many steps they are allowed to make.

In these lines, Hausmann & Klinger (2007) suggest reinterpreting the classical theories of development in what concerns the creation of externalities through industrialization. For instance, instead of being a result of forward and backward linkages (HIRSCHMAN, 1958), or investment complementarities requiring a "big push" (ROSENSTEIN-RODAN, 1958), the authors suggest regarding at them in terms of the flexibility of redeploying accumulated capabilities amongst different products.

It follows that development and growth would not depend on specializing even further in a few specific sectors, but rather on the diversification of production and the incorporation of new high-productivity activities. This result is regarded as a reflection of the technological capabilities accumulated by each country, so the more sophisticated and diversified an economy the more capabilities it has. In that case, the easier it is to adapt and recombine productive resources to the production of new goods.

The position of a country in the product space would inform about the productive knowledge that it has and the capacity to expand that knowledge by jumping to nearby products. An important source of path dependency comes from the fact that a country's initial location determines its ability to diversify and to move into more complex products. Poorer countries are located in the periphery, where moving to new product is harder to achieve. Even among countries with similar levels of development, different productive structures may put some of them on a continued path of structural transformation and other stuck in a dead end.

In these lines, a number of works have devoted efforts in analyzing the development trajectories of different countries and the factors that might influence the development of comparative advantage in new products. The next section review these works.

1.3.3 Recent developments

A large literature regard development as a path-dependent process that involves structural transformation and the accumulation of capabilities. Still, much of this literature lacked a strong empirical basis to support these ideas. More recently, this gap has been filled with complexity measures. A number of works have employed complexity indexes to proceed with different investigations concerning the development trajectories at regional or country level.

Many of these works investigated the development trajectories of different developing countries concerning the transformations of their productive structures. By analyzing different cases, these works provide evidence that countries follow coherent paths of development, based on increasing sophistication (e.g. Felipe, McCombie & Naqvi, 2010, Arnelyn & Felipe, 2011, Felipe et al., 2013, Felipe, Kumar & Abdon, 2013, Romero et al., 2015, amongst others).

Within this first strand of research, Felipe, McCombie & Naqvi (2010) in analyzing the case of Pakistan pointed to increasing sophistication of the productive structure as a way of relaxing the balance-of-payments constraints, enabling higher growth. In these lines, the authors pointed to the need of supply-side improvements that could increase the growth of sophisticated exports and to adopt a strategy guided by a country's capabilities in developing new possible successful activities.

Similarly, Arnelyn & Felipe (2011) point to the need of becoming less reliant on natural resource exports and carrying capability building efforts when analyzing the Sub-Saharan Africa's case. The authors verified that the region's low presence in the core products of the product space hampers the prospects for structural change, making a larger jump towards more sophisticated and diversified products far more challenging.

Felipe et al. (2013) showed that industrial policies in China have allowed the accumulation of product-specific capabilities, reflecting in diversification and increasing sophistication of its export basket[5]. During the late 1980s China set foot on the core of the product space, becoming highly sophisticated by 2006, developing RCA in a great number of products, particularly in electronics and machinery. Moreover, as a consequence of this developments, a measure of future export opportunities reveals that the country is likely to continue performing well.

As for the Indian case, Felipe, Kumar & Abdon (2013) find that the country's export basket presented a relatively high number of core products exported with RCA and was more diversified and sophisticated than would be expected considering the economy's level of development. This is argued to be a result of the country's labour laws and industrial policies that promoted the development of an industrial sector biased towards large-scale, capital-intensive and skill-intensive activities. However, this industrialization process failed to absorb the labour surplus from agriculture in the modern sectors of the economy. Contrary to India, China was

[5] Felipe et al. (2013) argue that without the accumulation of capabilities over the three decades under the planning system, the entrepreneurs would not respond to the incentives resulting from the marketing reforms.

able to absorb the labour surplus by developing labour-intensive sectors. As a result, in spite of India's higher income per capita in the late 1970s, China managed to become the world's factory and overcome India's income level (FELIPE et al., 2013).

Romero et al. (2015) have compared the development trajectories of Brazil and Korea after the 1980s. In describing their development paths, the authors presented the notion of revealed technological disadvantages (RCD) built upon a country's imports. Analyzed together with the notion RCA, it opens the possibilities for investigating possible bottlenecks, intra-industry trade and new potential industries. Hence, it would give a more clear view of how domestic production is performing in the local markets, including industries without RCA and remain left aside in most analysis.

Moreover, Romero et al. (2015) also allowed for changes in product space network associated with the division of labour reflecting the transformations in the patterns of international trade. Hence, instead of being held fixed through time, the shape of the network is allowed to change as means to understand how the structures of world production and trade have been modified through time.

Despite each country's idiosyncrasies in shaping their development paths, a number of works have turned to more generic factors affecting the development of new activities and new knowledge at city and country levels. A number of works have extrapolated these visions and proceeded with different investigations based on the works of Hidalgo et al. (2007), Hidalgo & Hausmann (2009) and (HAUSMANN et al., 2011).

Evidences on knowledge diffusion and geographical distance, have been drawn by Bahar, Hausmann & Hidalgo (2014). The authors show that neighboring countries are more likely to develop RCA in the same products, assuming that knowledge can be more easily diffused at short distances. In that case, countries should exhibit a geographically correlated pattern of comparative advantage and export growth.

On different lines, a number of works have dug dipper in the relatedness perspective embedded in the product space in addressing technical change. This strand of research explore different factors that would influence the probability of developing new activities or mastering new knowledge domains, incorporating a spatial perspective and taking the concept of relatedness as a major driving force behind technological change (e.g. Boschma, Balland & Kogler (2014), Bahar, Hausmann & Hidalgo (2014), Rigby (2015) and Petralia, Balland & Morrison (2017)).

Many of this studies employed the methods of economic complexity to patent data, as an alternative to capture knowledge complexity (e.g Balland & Rigby (2017)) or technological change (e.g Boschma, Balland & Kogler (2014), Petralia, Balland & Morrison (2017) at different levels of analysis[6]. Overall, they show that cities, regions and countries diversify into activities

[6] The strategies used to measure technological relatedness may differ by solely using patent registration (BOSCHMA; BALLAND; KOGLER, 2014) or also incorporating patent citations (RIGBY, 2015). However, evidences built upon US cities patent data have shown that findings are unlikely to change when using

and technologies related to their prior knowledge base and existing local technologies, in that the importance of relatedness (proximity) in shaping the knowledge dynamics is clear (BOSCHMA; BALLAND; KOGLER, 2014; RIGBY, 2015; PETRALIA; BALLAND; MORRISON, 2017).

At the city level, the evidence that the rise and fall of technological knowledge is conditioned by the existing knowledge base is provided by Boschma, Balland & Kogler (2014), while Balland & Rigby (2017) complement the authors' view by incorporating the possibility of knowledge flows between cities.

Balland & Rigby (2017) highlight that there is a wide variation in the knowledge complexity dynamics, showing that the more complex the knowledge, less geographically mobile it is. This would have important implications for trade and development, since low complexity knowledge would become less of a source of competitive advantage once it can easily move through space.

At the country level, Petralia, Balland & Morrison (2017) provide evidence that prior capabilities and relatedness shape possible paths of technological development. Most importantly, they show that this effects are stronger at earlier stages of development, in which diversification is more heavily constrained. At later stages, countries become able to make larger jumps and develop technologies less related to their current knowledge base. The type of technologies countries specialize differ at different stages of development. As they climb the ladder of technological development they gradually build-up new capabilities, while following clear patterns of specialization, by moving towards more complex and valuable technologies (PETRALIA; BALLAND; MORRISON, 2017).

However, developing countries face different obstacles that undermine technological diffusion, such as limited absorption capacity or the lack of technological efforts. To Poncet & Waldemar (2013) the absence of potential spillovers and domestic absorptive capacity would impact the relationship between sophistication and growth, while the apparent upgrading of the export basket could be a statistical illusion. Their results are interpreted as an evidence that structural and geographical disconnections between activities based on imported technology and those produced locally could hamper technological diffusion.

Still, many questions remain unexplored within this literature. For instance, Rigby (2015) points that although the importance of proximity in shaping the evolution of the knowledge basis is clear, we still need to understand what kinds of proximity are more important, how their structures vary and how to improve their measurement. Moreover, how regions or countries could transform their knowledge base toward greater complexity remains a fundamental question (BALLAND; RIGBY, 2017). In these lines, the determinants of economic complexity for instance, remain largely unexplored.

The positive impact of complexity in determining productivity growth have been reported

either alternatives of technological relatedness measures.

(HAUSMANN; HWANG; RODRIK, 2007; ROMERO, 2015). Moreover, Hartmann et al. (2017) have shown that productive structures are not only associated with income and economic growth (HIDALGO et al., 2007; HIDALGO; HAUSMANN, 2009; HAUSMANN et al., 2011), but also with income distribution. The authors suggest that a country's level of income inequality might be conditioned by its productive structure. The authors document a strong, robust, and stable correlation between a country's level of economic complexity and its level of income inequality. The results are robust even when controlling for various factors that are expected to explain cross-country variations in income inequality, such as the level of education, institutions, and export concentration. Moreover, they find that over time, countries that experience increases in economic complexity are more likely to experience decreases in their level of income inequality.

Henceforth, the economic complexity approach have provided important empirical support to fundamental problems of economic development, concerning a prolific area of research, to tackle different issues and renew old questions within the development literature. Nevertheless, it still lacks understanding the processes by which countries increase sophistication. A suitable explanation should be compatible with the idea that development is as process of learning how to produce more complex goods in the modern sectors. This process involve serious externalities that impact technological progress, upgrading a country's productive structure by incorporating higher technological content. Taking that into considering, the Schumpeterian literature serves as reference for understanding technological change in terms the mechanisms to promote technical change.

2 Schumpeterian literature

2.1 Introduction

Economic development and growth have long been analyzed in terms of a process of structural transformation, according to which economies change what they produce and how they do it. Mainly, this process feature shifts in the output structure, moving from low-productivity and low-wage sectors into high-productivity and high-wage activities. To promote such changes, technological learning and knowledge accumulation are a necessary condition. To understand the long term gains from changing an economy's pattern of specialization, Schumpeterian ideas have mainly focused on the sources, mechanisms and patterns of learning and capability building in generating technical progress. This perspective emphasise that knowledge is tacit and assumes technical progress to be endogenous. Its insights are also compatible with conditional convergence.

In investigating the processes by which countries accumulate knowledge and capabilities, Schumpeterian works have long emphasised the importance of innovations and endogenous technical progress. These are both found to exert important impacts on long-term growth and development by transforming the countries' specialization structures towards goods of higher technological content and scope for learning. Within this literature, the ability of generating technical change is apprehended both at the micro level and at the macro level through a series of concepts and measures of technological activities.

2.2 Technological effort and technical change

From the late 1950s onwards empirical research on factors affecting long-run growth grew steadily. The idea that countries different growth rates were attributed to technology have long been considered. Nonetheless, the seminal neoclassical works addressing growth dynamics assumed technical progress to be exogenous, so that technological activities would have no impact on a country's growth trajectory (e.g. Solow, 1956 and Swan, 1956).

Nonetheless, subsequent works investigating the mechanisms behind economic growth assumed knowledge to be less of a public good equally available to all, but rather tacit and difficult to acquire. This has put technological differences in the center of the explanations of variations in GDP per capita across countries. As a consequence, since knowledge is tacit, catching-up requires considerable efforts to succeed. For instance, knowledge may be created through research or learning, but it may also be acquired through education or training or even through imitation. It has been shown that some developing countries succeeded in promoting structural change and absorbing technology by engaging in capability building efforts (KIM, 1980; FRANSMAN; KING, 1984; LALL, 1987; LALL, 1992).

While some activities are associated with costly, prolonged, risky and unpredictable learning processes with strong externalities, others are relatively easy, short and predictable, with negligible externalities. Nonetheless, the former are the ones associated with higher income elasticities of demand and higher scope for further learning and upgrading. Therefore, greater gains would arise from specializing in the former, notably shaping the patterns of comparative advantage in favor of countries specialized in knowledge intensive activities (LALL, 2000).

From a microeconomic perspective, Schumpeterian literature emphasised the idea that technology and know-how are embedded in organizational structures, being difficult and costly to acquire. Therefore, efforts should be devoted to building capabilities and innovating at the firm level (NELSON; WINTER, 1982; DOSI, 1982). The micro insights in the Schumpeterian approach, on their hand, can be transposed to the macro level explaining growth and productivity performance. Hence, learning processes and increased productive capacity would generate endogenous technical progress, leading to long-term growth and development (e.g. Romer, 1990, Grossman & Helpman, 1991, Aghion & Howitt, 1992).

Moreover, at a macro level, Schumpeterian works have argued that productivity gap reflects technological differences across countries. Approaching the technological frontier, in turn would depend on a countries capacity to incorporate knowledge. This view is compatible with the notion of conditional convergence, according to which some sort of country's capacity measures such as human capital would shape the scope for catch-up (e.g. Abramovitz, 1986), Baumol, Blackman & Wolff, (1989)). This stresses the notion that from a technology-gap perspective, since knowledge is tacit, the path of technological learning is related to the capacity to acquire technologies and adapt them to local conditions.

2.3 Capabilities and learning

A central theme in the literature on the subject concerns the various capabilities that firms, industries, and countries need to generate in order to develop. Capabilities are associated with nontradable inputs, namely knowledge, which is tacit in nature and not equally available to all. Concepts such as "social capability" (ABRAMOVITZ, 1986), "technological capability" (KIM,1980;1997), "absorptive capacity" (COHEN; LEVINTHAL, 1990), and "innovation system" (EDQUIST, 1997; LUNDVALL, 1992; NELSON, 1993) have been suggested and an extensive empirical literature has emerged focusing on these aspects of development (see Archibugi & Coco (2005), Fagerberg & Godinho (2004).

The first attempts to study the relationships between technology, capabilities and development were carried by economic historians like Gerschenkron (1962), who put the requisites for successful catch-up in terms of "new institutional instruments". These refer to the organizations capable of identifying opportunities and mobilizing the necessary resources, so that countries could keep up with the new modern technology requirements. The first technology-gap theorists have focused on evidences from Europe and the United States (e.g. Gerschenkron, 1962). Subsequently, the Asian experience inspired new perspectives within this literature, emphasizing the significant role of certain efforts in building capabilities for development (e.g. Kim, 1980, 1997, Lall, 1992).

A number of works looked into the learning processes associated with the accumulation of capabilities, defining a series of concepts regarding the institutional requirements necessary for fostering knowledge accumulation and its utilization in the production of new technologies. These are put in terms of "technological capabilities" defined by (Kim, 1980;1997). Kim (1980), for instance regarded at the ability of local firms to replicate, use, diffuse foreign technologies, as well as creating their own. The ability to do so would involve not only organized efforts to conduct R&D but also the capacity to exploit technologies commercially and diversify the country's exports portfolio.

There are also factors that influence the technological capabilities of firms at the country level, which may include their policy regimes, skill endowments and institutional structures (LALL, 1992). At country level, technological capabilities are generally defined as the capacity of a given country to generate, use, adapt, absorb, and transmit knowledge to develop and master, in an effective way, technological innovations directed to promoting growth (KIM, 1980; LALL, 1992).

Lall (1992) was the first to address the concept of technological capabilities at the national level, regarding the national factors that condition firm-level capabilities. Considering the existence of externalities and linkages between them, synergies would likely be found. Hence, there should be common elements in the firms' response to institutional arrangements, policies and market conditions that substantiate the notion of national differences in technological capabilities. These, in turn, would reflect in the countries' productivity, growth and trade performances (LALL, 1992).

The effective utilization of a country's technological capabilities, in turn, would depend on the incentives structure that arise from the institutional set up of the economy. Both incentives and capabilities operate within an institutional framework, which can shape the behavior and expectations of the economic agents, similarly to what Abramovitz (1986) called social capabilities. The interplay of all these factors would determine at the firm level, how learning processes take place to cope with industrial technologies as well as determine, at the national level, how countries employ their factor endowments and grow dynamically.

A number of works also acknowledge that learning processes are associated with using, diffusing and adapting technologies developed elsewhere to local conditions. In these lines, the process of developing capabilities have been regarded in terms of absorptive capacity. It resembles the notion of technological capabilities and are usually used interchangeably. The definition of absorptive capacity is given by "the ability of a firm to recognize the value of new information, assimilate it, and apply it to commercial ends" (COHEN; LEVINTHAL, 1990, p. 128). Hence, it refers to the organization's ability to absorb knowledge, as well as to exploit it commercially. This concept became more popular in the applied literature of development regarding the firm's ability to absorb knowledge by incorporating measures of R&D expenditure.

Within the Schumpeterian scheme, the Evolutionary strand took part in the empirical and theoretical investigations of technical change in developing economies. From this perspective technological change has been analyzed as the outcome of innovation and learning within organizational structures (especially firms) and their interaction with the environment (NELSON; WINTER, 1982; DOSI, 1982). Rather than something that exists in the public domain and can be exploited by anybody everywhere free of charge, technological knowledge, whether created through learning or organized R&D, is deeply rooted in indigenous specific capabilities of private firms and their environments. According to these scheme, the availability of the required capabilities for development would depend on the institutional set up of the economy that shape the creation and effective use of technology.

According to an evolutionary point of view, development is assumed to be shaped by a historical process with strong path-dependency which rely on the relationship between technological, social and institutional factors underlying technological development. Therefore, it suggests addressing technological capabilities in a broader sense, also considering other social, institutional and economic factors needed to absorb R&D efforts. Country's singularities determine its technological capabilities and innovation capacity. The resulting in institutional arrangements are called National Innovation Systems (NIS) (LUNDVALL, 1992; NELSON, 1993; EDQUIST, 2004). In these lines, the development of technological capabilities depends on a web on interaction between firms, agents, institutions and organizations.

The empirical studies associated with this perspective use composite indicators as means to assess the various aspects of technology in measuring the degree of development of NISs and their capabilities. Although it still remains a diffused approach, some indicators have been consolidated in the literature. It is the case of patent statistics, scientific publications, proportion of new goods in international trade, licensing fees, human resources and ICT infrastructure, for example (ARCHIBUGI; COCO, 2005; ARCHIBUGI; DENNI; FILIPPETTI, 2009). Still, most of these indicators are found to be strongly correlated with each other, hence aggregated measures of country capabilities could be used to compare countries summing the many aspects of capabilities.

From a macro perspective cross-country differences are regarded through a single factor, namely R&D (ROMER, 1986; GROSSMAN; HELPMAN, 1990; AGHION; HOWITT, 1992). Works on this strand emphasise the importance of endogenous technical progress as the main driver of productivity increases, according to which a variety of works show a positive impact of research intensity on technological progress, by promoting output and productivity growth (e.g. Fagerberg,1987, Fagerberg & Verspagen, 2002, Ha & Howitt, 2007). In this vein, models incorporate learning by doing and knowledge cumulativeness in explaining economic performance.

2.4 Endogenous technical progress

From the 1970s onwards several works on cross-country differences in growth and development emerged, focusing on technology as the driving force behind why growth rates differ. A large body of literature investigating the role of technology for economic development rests on Schumpeter's (1934, 1943) contributions about innovation and product differentiation. These create temporary monopolies allowing for extraordinary profits to innovators. Therefore, entrepreneurs find strong incentives to invest on R&D as means to innovate. The role of R&D stands out when investigating the determinants of economic growth particularly from a macro perspective, according to which research intensity is usually employed to capture the aggregate efforts in generating technical progress.

Schumpeterian growth models assume that technology is intentionally accumulated through a series of efforts in conducting technological activities (e.g. Romer, 1990; Aghion & Howitt, 1992, 1998; Ha & Howitt, 2007, Madsen, 2008). The impact of research intensity on technical progress have been tested throughout the literature in a variety of forms. Some works regress research intensity against output growth, assuming that it explains technical progress (FAGERBERG, 1987; FAGERBERG; VERSPAGEN, 2002). Other works use productivity growth as the dependent variable, usually measured by total factor productivity (TFP), assuming that research intensity impacts productivity growth (HA; HOWITT, 2007; MADSEN, 2008). Overall, empirical evidence from most of these works corroborate the role attributed to research intensity in increasing productivity and output growth.

Normally, research intensity is measured by patents per worker or by the ratio of R&D to output, being both patents and R&D closely correlated (FAGERBERG, 1987; GRILICHES, 1990). Throughout the literature, the impact of research intensity on technical progress was tested in a variety of forms. For instance, Fagerberg (1987) and Fagerberg & Verspagen (2002) use output growth as a dependent variable, while Ha & Howitt (2007) and Madsen (2008) test the impact of research intensity on Total Factor Productivity (TFP) growth.

Embedded in research intensity measures, on its hand, would be a series of indigenous characteristics that circumstantiate technological activities. These may refer to differences in entrepreneurial capacity, institutional set, government regulation, access to finance, access to inputs, average firm size and market size, amongst other factors. Their impact on technological progress would indirectly be captured through national technological activities measures (ROMERO, 2015).

Lastly, another important face of R&D concerns its role in increasing the scope for technological absorption in an economy (COHEN; LEVINTHAL, 1990; GRIFFITH; REDDING; REENEN, 2004). It has been shown that national technological activities may affect more than the innovation ability of an economy, but also its capacity to transfer technology from frontier countries. In fact, since innovating is easier than imitating, strong potential for productivity growth can be extracted from research intensity efforts. This conducts to yet another important determinant of productivity growth, which is technological transfer. Its importance is emphasised in many Schumpeterian works (POSNER, 1961; ABRAMOVITZ, 1986; VERSPAGEN, 1991; GRIFFITH; REDDING; REENEN, 2004) that suggest that productivity gaps between countries reflect technological differences amongst them, opening up opportunities for technological transfer.

2.5 Technological transfer

Supported by Schumpeter's (1934, 1943) microeconomic ideas on innovation and imitation, at the aggregate level, innovation and technological change have being regarded in the light of the productivity gaps between leader and follower economies (e.g. Posner, 1961; Abramovitz, 1986; Verspagen, 1991; Griffith, Redding & Reenen, 2004; Vandenbussche, Aghion & Meghir, 2006).

The technology-gap hypothesis initially stated by Posner (1961) suggests that countries at the technological frontier relies more heavily on innovation than on imitation to promote productivity growth. The opposite holds for following countries, which mostly rely on imitation, absorbing the technology created in the frontier. Backward countries may benefit from this condition, since it is easier to absorb foreign technology than to innovate. Hence, follower countries that are initially more backwards tend to catch-up faster and as its productivity level gets closer to that of the leader, the potential for growth decreases. That is, follower countries have the potential to make larger leaps in the technological content embodied in the capital stock, ensuing higher rates of productivity growth compared to leader economies. Once the productivity level converges towards that of the leader, the possibility of making larger leaps gets smaller and their growth potential weakens (POSNER, 1961; ABRAMOVITZ, 1986).

The possibility of narrowing the gap in productivity and income levels relative to a leader country is promising, since they may extract high growth potential from absorbing technologies developed in the frontier economies. However, this process is by no means automatic. Path dependency and cumulativeness create strong inertia in the patters of learning and specialization, so that closing the gap requires a series of efforts related to absorbing, adapting, using and improving upon foreign technology. These view are also compatible with the notion of conditional convergence (FAGERBERG, 1994).

Convergence may not occur considering the path-dependency and cumulativeness of the learning process and specialization patterns. Hence, some persistent asymmetries in mastering production processes and introducing innovations are expected. For instance, this is regarded by Abramovitz (1986) in the light of the concept of what he called "social capabilities" to societal characteristics that may keep backward economies from making a technological leap, requiring efforts for improving education, infrastructure and technical competence, for example. It have been roughly proxied by years of education, although its conception contemplated a much more comprehensive picture.

The larger the technology gap between frontier and backward economies, the higher the potential for rapid productivity growth through technological absorption (POSNER, 1961; VERSPAGEN, 1991; GRIFFITH; REDDING; REENEN, 2004). In that case, the path of technological learning depends on the capacity to acquire technologies and adapt them to local conditions. To benefit from the opportunities for technological transfer from leader to follower economies depends if they are capable of absorbing foreign technology.

The level of initial productivity is usually used as a proxy for the technology gap in cross-country analysis (FAGERBERG, 1987) or measured as the ratio between the country's productivity and the frontier's productivity (AMABLE, 1993; FAGERBERG; VERSPAGEN, 2002; GRIFFITH; REDDING; REENEN, 2004). In both cases, a negative relationship between productivity growth and the size of the gap is found, endorsing the notion that technological transfer contributes to closing the gap.

Following these lines, a number of works have investigated the factors that increase technological absorption. For instance, Acemoglu, Aghion & Zilibotti (2006) showed that higher regulation increases technological absorption of countries far from the technological frontier and decreases as countries approach the frontier. On its turn, Vandenbussche, Aghion & Meghir (2006) found that countries closer to the frontier feature stronger effects of skilled human capital on growth. Griffith, Redding & Reenen (2004), in turn, found that higher research intensity allows countries to benefit more from the size of the technology gap in absorbing technology. Since some knowledge is tacit and difficult to acquire without direct investigation, understanding and assimilating the discoveries of others would depend on efforts in building absorptive capacity. Not only that, laggard countries that heavily invest in R&D are able to catch-up faster.

GDP per capita has been used as a proxy for productivity by a number of authors and different variables have been regressed against it as means to test the different determinants of productivity. Authors within the technology gap debate have employed GDP per capita as an independent variable proxying for the scope of catch-up (e.g. Abramovitz, 1986). Indeed the existence of productivity gaps creates the potential for fast growth.

Introducing an education variable into the regression, for instance, substantiated the scope for catch-up (e.g Baumol, Blackman & Wolff, 1989). This test also goes in line with a series of endogenous growth models incorporating human capital as a source of externalities affecting technical progress (NELSON; PHELPS, 1966; LUCAS, 1988; ROMER, 1990). Human capital is assumed to allow for a more rapid rate of incorporation of new products (ROMER, 1990). It also plays a key role not only in generating innovations, but also in the absorption of foreign knowledge[1]. If innovations produce externalities, then education also yields externalities by stimulating innovations. In fact, education is found to speed technological diffusion (NELSON; PHELPS, 1966). In the same vein, Griffith, Redding & Reenen (2004) provide evidence that human capital allows to better exploit the technology gap, by generating externalities not only in producing innovations but also in enhancing absorptive capacity.

The impact of such variables on productivity and per capita growth have been widely explored in cross-country regressions of the late 1970s and 1980s onwards. For instance, researchers inspired by the technology-gap studies assume that GDP per capita reflects the degree of technological sophistication and the scope for catch-up. On the other hand, adherents of the Solow model include GDP per capita in growth regressions as a proxy for the capital-labour ratio. This usually include GDP per capita, the growth of the labour force, some proxy for human capital, as well as some possible additional variables assumed to affect growth. The latter may comprise country size, openness to trade and the share of public sector in GDP. The relationship between different institutions and productivity growth, in turn, has been apprehended by variables such as property rights, type of legal system, corruption and bureaucracy. Still, these latter measures have been found not to be as robustly correlated to growth as the former (FAGERBERG, 1994).

[1] In these lines, if human capital have an impact on catch-up, it would also play a key role in determining productivity growth (NELSON; PHELPS, 1966).

3 Productive complexity and absorptive capacity

3.1 Introduction

An extensive literature, notably amongst the Schumpeterian strand, acknowledge that development is a result of learning and capability accumulation, by which countries become able to transform and upgrade its productive structure. This concerns a highly path dependent process which relies on a country's knowledge stock and production experience in recombining productive resources to the creation of new dynamic activities. Moreover, transforming developing countries' specialization patterns would depend on a context of knowledge absorption and high assimilation by which the capacity to employ new methods of production and new inputs is increased, resulting in significant upgrading. Moreover, this process can rely on borrowing, imitating, mastering and improving on advanced technology used by frontier countries, stemming productivity growth. Therefore, since imitating is easier than innovating, backward economies would be able to experience higher productivity increases than frontier economies, growing at a faster pace (ABRAMOVITZ, 1986; GRIFFITH; REDDING; REENEN, 2004).

On its hand, Hausmann, Hwang & Rodrik (2007) and Hausmann et al. (2011) have provided new empirical evidence that the efforts to accumulate new capabilities are more likely to succeed if countries expand and diversify their productive knowledge. According to these approach, an economy would be able to produce solely the goods which it has the requisite knowledge and capabilities. However, countries may not have some specific sets of capabilities precisely because the products that require them are not present, restricting the possibilities of jumping to new activities. Nonetheless, the concept of absorptive capacity may give support to investigate the process by which developing economies diversify by restoring the notion of technological transfer.

The insights provided by the economic complexity approach may relate to the technology-gap views on knowledge transfer by attributing a role to the productive structure in this process. More complex production sets are assumed to reflect the diversity of productive knowledge. A more robust basis for learning, on its hand, may increase assimilation and technological absorption, promoting significant upgrading. Henceforth, the present chapter aims to investigate if the type of specialization of a country would impact on its capacity of closing the gap with frontier countries, by enhancing absorptive capacity. This hypothesis is presented in more detail next.

3.2 Absorptive capacity and economic complexity

Cohen & Levinthal (1990) states that learning is cumulative and learning performance increases when the object is related to previous knowledge. Hence, the diversity of knowledge also plays an important role, in that the likelihood that new information will relate to what is already known increases if there is a diverse background. Put in other words, diversity of knowledge would allow a more robust basis for learning, facilitating new associations and creating more linkages, also with important reflections on innovative capacity.

More recently, the role of relatedness between products and technologies and its effects on diversification and structural change have gained increased attention (FRENKEN; OORT; VERBURG, 2007; HIDALGO et al., 2007; SAVIOTTI; FRENKEN, 2008). These works acknowledge that diversification possibilities depend on the degree to which products or technologies are connected to each other, being the nature of these links based on the knowledge, skills and capabilities required in production. Technological change, therefore, would follow according a path dependent process in which the production of new knowledge is subject to the previous knowledge available.

A close correlation between productive diversification and economic sophistication have been reported in recent works (FELIPE et al., 2012). According to Hausmann et al. (2011), diversified productive structures would be a reflection of knowledge diversity. The more knowledge an economy has, more easily it can redeploy its capabilities to the production of new goods. This would have a direct link with the fact that prior knowledge provides the ability to recognize the value of new information, assimilate it and exploit it commercially. That concerns what Cohen & Levinthal (1990) define as absorptive capacity.

It is argued that the ability to imitate differ across backward economies, depending on the diversity of knowledge incorporated on their productive structures. Specialization patterns oriented towards high knowledge would provide better prospects for a country to benefit from technological transfer, by laying down the basis to identify diversification opportunities supported by prior knowledge and capabilities. Moreover, capabilities could be more easily accumulated if they can be combined with the ones already present in the production of other goods (HAUSMANN et al., 2011).

To investigate the effects of sophistication on the absorptive capacity, the economic sophistication index is transposed to the industry level following Romero & Britto (2018), providing a measure of the production sophistication of a given country in each industry. The industry sophistication index (IEXPS) is calculated as the weighted average of Product Sophistication (PS), a variation of the IEXPY, which is based on PRODY. The authors suggest that PS would be a preferable index of economic sophistication over PRODY, because it partially corrects some distortions generated by the latter, in attributing high sophistication values to low-tech and primary industries. IEXPS is calculated for each product i in industry j and country c according the following:

$$IEXPS_{cit} = \sum_{j} \left(\frac{x_{ckt}}{\sum_k x_{ckt}} \right) PS_k \tag{3.1}$$

The PS index, on its turn, is calculated using the first iteration between diversity and ubiquity, following the Method of Reflections described by Hidalgo & Hausmann (2009).

In the following investigation it is expected that higher IEXPS produces a stronger effect in increasing absorptive capacity the more backward the countries. These are the ones with less with diversified productive structures, therefore, facing higher constraints in terms of the available capabilities necessary for jumping to the production of new more sophisticated goods. As countries develop, they gradually increase their capabilities set and become less bounded by the requisites necessary for entering a new line of production.

The empirical tests follow the estimation strategy used by Griffith, Redding & Reenen (2004) in investigating the role of research intensity in fostering absorptive capacity. As discussed in chapter 2, since productivity differences opens up opportunities for technological transfer, the more backward the country, the faster it would be able to approach the productivity frontier. The authors' modeling strategy follow the rationale found in endogenous growth models (e.g. Romer, 1990 and Aghion & Howitt, 1992), starting by defining a standard production function according to which value added (Y) in each sector is produced with labour (L) and capital (K):

$$Y_{cit} = A_{cit} f\left(L_{cit}, K_{cit}\right) \tag{3.2}$$

where A is an index o technical efficiency, or total factor productivity (TFP), and $f(\cdot, \cdot)$ is assumed to be homogeneous of degree 1 with decreasing marginal returns.

Following the empirical literature on on R&D and productvity growth at the industry level (Griliches, 1980), TFP is assumed to be a function of the knowledge stock G. Assuming small rates of R&D, TFP growth may be expressed by taking logarithms and differencing in time by:

$$\Delta ln A_{cit} = \rho \left(\frac{R}{Y} \right)_{cit} + \gamma X_{cit-1} + u_{cit} \tag{3.3}$$

where $\rho \equiv (dY/dG)(G/Y)$ is the rate of return to R&D, being G the knowledge stock, X is a vector of control variables (human capital and international trade) and u_{cit} is the stochastic error. The next step is to introduce technology transfer as a source of productivity growth for laggard countries, as well as incorporate the rate of return fo R&D as a function of the distance from the technological frontier.

$$\hat{TFP}_{cit} = \rho_1 \left(\frac{R}{Y}\right)_{cit-1} + \underbrace{\delta_1 ln \left(\frac{A_F}{A_c}\right)_{it-1}}_{\text{technology transfer}} + \underbrace{\delta_2 \left(\frac{R}{Y}\right)_{cit-1} * ln \left(\frac{A_F}{A_c}\right)_{it-1}}_{\text{absorptive capacity}} + \gamma X_{cit-1} + u_{cit} \tag{3.4}$$

The first term captures the impact of density on productivity growth. The second term captures technology transfer, measured by the size of the gap relative to the productivity in the frontier. The larger the gap, the larger the possibility of technological transfer, implying in a positive coefficient δ_1. The third term captures the absorptive capacity, so the larger the gap and higher the density, the greater the potential for technology transfer, which implies in a positive coefficient δ_2. In that case, a positive and significant coefficient have showed that besides incrementing a country's innovation capacity, research intensity could also enhance technological absorption in research intensive activities, playing an important role in closing the productivity gap.

To implement the estimation strategy employed by Griffith, Redding & Reenen (2004) firstly the author's specification will be reassessed using a panel set covering thirty year since 1976. In the sequence, IEXPS will be estimated as means to investigate if the composition of production plays any role in affecting absorptive capacity.

3.3 Data and method

3.3.1 Data and sources

The productivity measure used in this investigation, namely Total Factor Productivity (TFP), is calculated according to a growth accounting framework in which output growth is decomposed into its constituent parts, namely capital inputs (K_{it}), labour inputs (L_{it}) and technology (A_{it}), all detailed by industries. The latter component of output growth is usually referred to as "multifactor productivity", or simply TFP. It captures the proportion of output growth that is not explained by neither of the prior inputs. This are all incorporated in a translog production function in which the contribution of each input is given by the product of its growth rate and its share in total costs[1].

$$\Delta lnY_{cit} = \alpha^K_{ct} \Delta lnK_{cit} + \alpha^L_{ct} \Delta lnL_{ict} + \Delta lnA_{cit} \tag{3.5}$$

where α denotes the cost shares of each input.

Measuring TFP levels involves a number of issues concerning the measurement of value added, capital, labour and their shares in value added. Also adequate price deflators and

[1] The form of the production function is based on the work of (CAVES; CHRISTENSEN; DIEWERT, 1982).

Purchasing Power Parities (PPPs) converters are needed to make international data comparable across time. These, together with information on output, capital stocks and labour at the two-digit industry level is obtained from the EU KLEMS database (version March 2011) (EU KLEMS, 2011). This information has been gathered from national statistical institutes with attention to several problems involving measuring output and productivity at the industry level (O'MAHONY; TIMMER, 2009). In the authors' calculations, value added measures account for intra sectors exchanges, while capital stock is calculated through the perpetual inventory method. Changes in the quality and the composition of different types of capital are also accounted for, as well as adjustments for capital utilization. Labour inputs also consider differences in the workforce skills, as well as account for self-employed workers (O'MAHONY; TIMMER, 2009).

Amongst the advantages of the EU KLEMS database figure the fact that it has been harmonized to present the same industrial classification, price concepts and inputs definitions (O'MAHONY; TIMMER, 2009, p. F379). Moreover, additional statistics from national censuses and surveys have been used to complete missing information, as well as care has been taken to ensure that the series are time consistent. Lastly, all the value added data has been deflated using industry-level quality-adjusted price indexes calculated based on each country's national accounts.

This database covers the period between 1970 to 2007 disaggregated into 71 industries classified according to the International Standard Industry Classification (ISIC) Rev.3 and up to 30 OECD countries. Capital stock is the most restrictive variable and, hence, guides the selection of countries and time coverage. Table 1 presents the manufacturing industries for which data is most completely available[2].

After cleaning the dataset the resulting sample comprises the years between 1976 – 2006 and includes 11 OECD countries: Australia, Austria, Denmark, Finland, Germany, Italy, Japan, Netherlands, Spain, United States and United Kingdom[3]. The 13 manufacturing industries contemplated are listed in Table 1.

This data is used to calculate TFP growth rates and the respective country-industry distances to the frontier according to Griffith, Redding & Reenen (2004). Variables were transformed from national currencies to 1995 US dollars using industry-specific PPPs from the Groningen Growth and Development Centre (GGDC) Productivity Level Database (INKLAAR; TIMMER et al., 2008), following the methodology of Timmer, O'Mahony & Ark (2007, p. 50-1).

Growth decompositions usually tries to embody, as far as possible, the technological progress embedded in each factor itself, adjusting for shifts in quality and variations in its composition. For instance, Griffith, Redding & Reenen (2004) incorporate differences in labour

2 The value added accounting identity was checked for each industry, year, and country to check for consistency (see Felipe & McCombie, 2005, Felipe, Hasan & McCombie and 2007).

3 For Czech Republic, Portugal, Slovenia, and Sweden data is available staring from 1995 and hence were not included in this chapter estimations

Table 1 – KLEMS Industries

ISIC Rev.3	Description	Short Name
15t16	Food products, beverages and tobacco	
15	*Food products and beverages*	Food
16	*Tobacco products*	
17t19	Textiles, textile products, leather and footwear	
17	*Textiles*	
18	*Wearing apparel, dressing and dying of fur*	Textiles
19	*Leather, leather products and footwear*	
20	Wood and products of wood and cork	Wood
21t22	Pulp, paper, paper products, printing and publishing	
21	*Pulp, paper and paper products*	Paper
22	*Printing and publishing*	
23	Coke, refined petroleum products and nuclear fuel	Fuels
24	Chemicals and chemical products	Chemicals
25	Rubber and plastics products	Plastics
26	Other non-metallic mineral products	Minerals
27t28	Basic metals and fabricated metal products	
27	*Basic metals*	Metals
28	*Fabricated metal products, except machinery and equipment*	
29	Machinery, nec	Machinery
30t33	Electrical and optical equipment	
30	*Office, accounting and computing machinery*	
31	*Electrical machinery and apparatus, nec*	Electrical
32	*Radio, television and communication equipment*	
33	*Medical, precision and optical instruments*	
34t35	Transport equipment	
34	*Motor vehicles, trailers and semi-trailers*	Transport
35	*Other transport equipment*	
36t37	Manufacturing nec; recycling	
36	*Furniture*	Recycling
37	*Recycling*	

Note: Industries marked in italics are considered only at the more aggregated level.

Source: Adapted from O'Mahony & Timmer (2009, p. F400)

qualification, while O'Mahony & Timmer (2009) employ hours worked and characteristics such as age, gender and educational attainment. Here labour inputs were measured based on total hours worked by persons engaged in production. Since the shares of hours worked broke-down by skill levels (high, medium and low skills) were not available for the US, these were not incorporated in the TFP measures. Capital stocks, on their hand, were split into Information and Communication Technology (ICT) assets and Non-ICT assets[4]. Both types of assets were weighted by their corresponding shares in capital compensation. In doing so, no assumptions about the returns to scale of each asset are required (ROMERO; BRITTO, 2017). The remaining output growth not explained by any of the former inputs is captured by the multifactor productivity term. Contrary from O'Mahony & Timmer (2009), who assume that TFP account only for disembodied technical progress, here TFP levels are presumed to incorporate various factors, including, for instance,

[4] ICT assets include computers, communication equipment and software. On its hand non-ICT assets may include transport equipment, other non-ICT machinery and equipment and non-residential structures

differences in production technology and internal and external returns to scale (ROMERO; BRITTO, 2017). As it is most common in the literature, TFP growth calculations employ a log-level index derived from a translog production function:

$$T\hat{F}P_{cit} = ln\left(\frac{Y_{cit}}{Y_{cit-1}}\right) - \frac{1}{2}\left(\alpha^{L}_{cit} + \alpha^{L}_{cit-1}\right) ln\left(\frac{L_{cit}}{L_{cit-1}}\right) - \frac{1}{2}\left(\alpha_{cit} + \alpha_{cit-1}\right) ln\left(\frac{K_{cit}}{K_{cit-1}}\right) \tag{3.6}$$

where Y_{cit} is the total value added, L_{cit} corresponds to the total hours worked by persons employed, K_{cit-1} correspond to the capital assets (ICT and non-ICT).

To measure the TFP distance of a country c to the frontier F, an analogous log-level index for comparisons between TFP levels is calculated following Griffith, Redding & Reenen (2004). Firstly, to construct a measure of the technology gap, each country TFP is evaluated relative to a common point, namely the geometric mean of the TFPs of all countries in a given sector i. This is calculated for each country-industry pair at time t according to Equation 3.7.

$$MTFP_{cit} = ln\left(\frac{Y_{cit}}{\bar{Y}_{it}}\right) - \frac{1}{2}\left(\alpha_{cit} + \bar{\alpha}_{it}\right) ln\left(\frac{L_{cit}}{\bar{L}_{it}}\right) - \left[1 - \frac{1}{2}\left(\alpha_{cit} + \bar{\alpha}_{it}\right)\right] ln\left(\frac{K_{cit}}{\bar{K}_{it}}\right) \tag{3.7}$$

where $\bar{Y}_{it}$, $\bar{L}_{it}$ and $\bar{K}_{it}$ refer to the geometric means of output, labour and capital, respectively. Next, the frontier (F) is defined as the country with the highest TFP level relative to the geometric mean in each industry i, denoted by $MTFP_{Fit}$. The size of the technology gap is then calculated by Equation 3.8.

$$TFPGAP_{cit} = MTFP_{Fit} - MTFP_{cit} \tag{3.8}$$

The information on TFP growth and the size of the productivity gap is combined with R&D data at the industry level gathered from the OECD Analytical Business Enterprise Research and Development (ANBERD, 2012). From 1976 to 1986 data is available according to the ISIC Rev.2 classification, whilst from 1987 to 2006 information is available according to ISIC Rev.3. Data was made compatible according to Table 13 in Appendix B. To obtain research intensity measures, R&D data in current national units was divided by value added, also in current national units, extracted from EU KLEMS (2011).

Finally, the IEXPS measures were calculated according to Romero & Britto (2018). The indexes were calculated for the period of 1984 – 2006 as a result of the compatibilization between price data from Feenstra & Romalis (2014), available between 1984 and 2011, and EU KLEMS data covering the period between 1976 and 2006. The final sample comprises 13 industries and seven countries, Austria, Denmark, Finland, Germany, Netherlands, Spain and United Kingdom. Data on GDP per capita (2011 PPP$) is from the World Development Indicators WDI (2017).

Lastly, trade data classified according to the Standard International Trade Classification (SITC) Rev.2 at the 4-digits level, is from the UN Comtrade (2015) gathered from 1976 to 2006[5].

3.3.2 Data description

In Table 2 it can be seen that throughout the years average TFP growth rates featured some heterogeneity across industries. Growth rates mostly declined within low-tech industries. For instance, in the beginning of the period "Textiles", "Plastics" and "Metals" had higher TFP growth rates compared to "Machinery" and "Transport". The latter, in turn, grew along the period, being comparable to the "Chemical" and "Electrical" industries by 2001 – 2006. These are the industries featuring higher TFP growth rates in the periods analyzed.

Table 2 – Mean annual TFP growth rates by industry (1979 – 2006)

	1979 – 1985	1986 – 1990	1991 – 1995	1996 – 2000	2001 – 2006
Food	0.012	0.010	0.012	0.001	0.006
Textile	0.035	0.007	0.013	0.017	0.017
Wood	0.019	0.008	0.010	0.009	0.012
Paper	0.017	0.008	0.010	0.007	0.009
Fuels	-0.010	-0.004	0.007	-0.014	-0.031
Chemicals	0.050	0.027	0.029	0.021	0.022
Plastics	0.031	0.022	0.012	0.009	0.017
Mineral	0.016	0.016	0.009	0.015	0.025
Metals	0.034	0.016	0.022	0.009	0.017
Machinery	0.018	0.021	0.013	0.004	0.029
Electrical	0.048	0.049	0.052	0.053	0.044
Transport	0.017	0.018	0.025	0.014	0.028
Recycling	0.009	0.019	-0.002	0.010	0.012

Source: Author's elaboration based on EU KLEMS (2011).

To account for the TFP growth relative to the frontier, each country's TFP as a proportion of TFP in the frontier is calculated by taking the exponent of the negative of the $TFPGAP_{cit}$, as in Griffith, Redding & Reenen (2004, p. 887). Hence, for the frontier country, relative TFP is equal to 1 and the smaller the relative TFP, the further a country is to the frontier. Table 3 identifies the frontier country and the country with the second highest relative TFP, as well as reports the mean and standard deviation for the years of 1979, 1992 and 2006.

Looking at the relative TFP means in the three years depicted in Table 3 it is possible to note that some sectors have faced increases in relative TFP means as well as decreases in its standard deviations. For instance, that is the case for "Transport", "Machinery" and "Minerals". Other industries such as "Textiles" and "Chemicals", however, have faced decreasing relative TFP means and increasing standard deviations. On its hand "Plastics" and "Recycling" had increases in both mean and standard deviations of relative TFP levels. Lastly, "Metals" and

[5] UN Comtrade (2015) data classified by the SITC Rev.2 was compatibilized with the 13 industries covered by the EU KLEMS sample classified according to the ISIC Rev.3 2-digits. The correspondence employed is described in Table 13 presented in Appendix B.

"Electrical" industries presented increases until the 1990s and then its relative TFP levels changed direction, indicating that they have been closing the gap until the mid-1990s and afterwards diverged. [6].

A special case amongst the considered industries is the "Electrical" sector. Until the mid-1990s it experienced considerable catching-up relative to the frontier. In 1995 the United States assumed the technological leadership in this industry, leapfrogging other European countries, notably Germany, which had been the technological frontier throughout the 1980s.

It should be mentioned that the Electrical sector comprises mostly Information and Communication Technology (ICT) goods that led to important structural improvements in ICT-producing, as well as ICT-using activities, with serious impacts on productivity. This have reflected on major changes in the comparative growth performance of Europe and the United States in the second half of the 1990s. Figure 1 illustrates the impact of such developments in the relative TFP for the electrical sector over the years. It is clear that all countries (except Finland) fell behind the US technological leadership from the mid-1990s onwards.

A large number of works based on growth accounting have investigated the rapid US catch-up and Europe's falling behind focusing on investments in ICT goods. They verified that since 1995 the United States labour productivity growth rates nearly doubled, whereas European growth rates declined. Such strong growth performance was attributed to the increasing investment in ICT goods, as well as to the resulting improvements in TFP, which strongly supported aggregate labour productivity growth (JORGENSON; STIROH, 2000; OLINER; SICHEL, 2000). That was the case for the United States and also Finland (PILAT, 2003).

Besides the TFP growth in ICT goods manufacturing, TFP acceleration in the ICT-using service industries also appeared to be important. As more detailed industry-level data became available, Triplett & Bosworth (2004) and Jorgenson et al. (2005) showed that ICT-using service industries such as trade, finance and business services were the biggest contributors to aggregate ICT capital deepening.

Even after parts of the ICT sector entered a down-turn, ICT is commonly considered to have contributed to a structural improvement in certain OECD countries. For instance, within our sample Australia and the United States figure amongst the key examples of ICT-led growth. This suggests that the impacts of ICT on productivity could persist, so that ICT would remain a key factor for overall growth performance (PILAT, 2003).

United States TFP growth rates levels increases consistently since the beginning of the 1990s, nevertheless, a more clear depart from Germany occurs in 1995, when German TFP growth rates take a plunge and departs from US growth rates. A similar trend is observed for

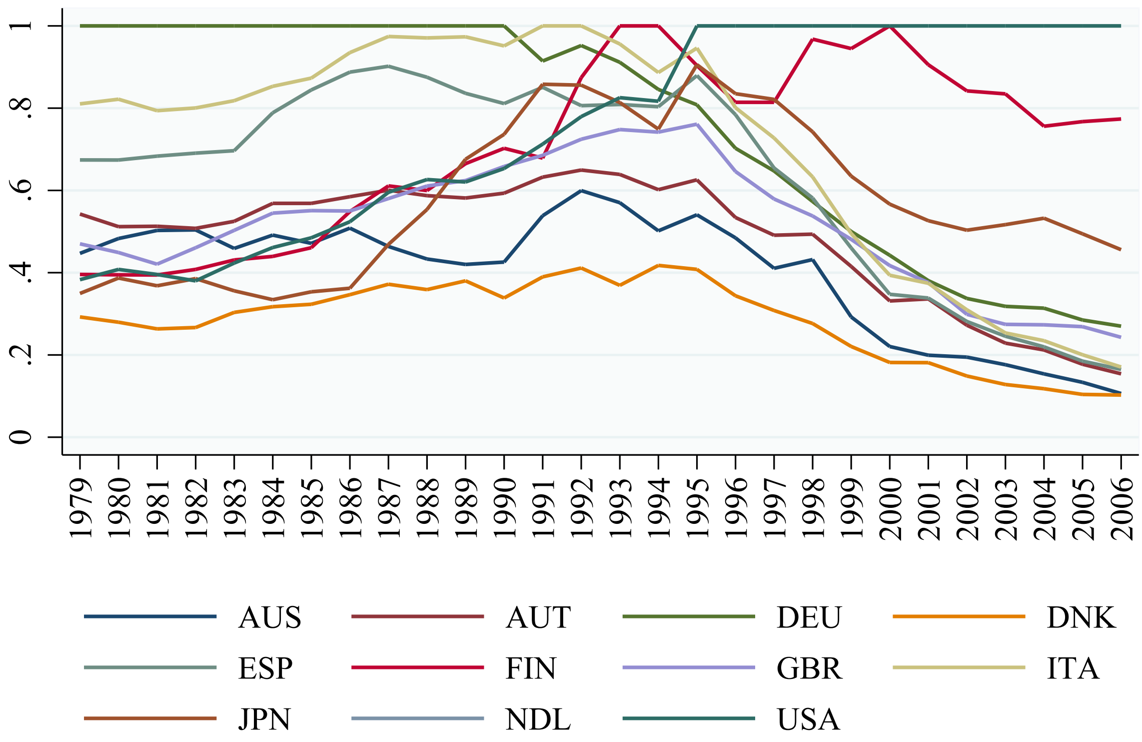
[6] Griffith, Redding & Reenen (2004) point to β-convergence and σ-convergence in relative TFP levels. The former refers to cross-section correlation between growth rates and initial levels of relative TFP. The latter refers to the evolution of the sample standard deviation of relative TFP. Lower standard deviations over time woul be an indication of σ-convergence in relative TFP levels within manufacturing industries.

Table 3 – Relative TFP and frontier countries

ISIC Rev.3		1979	1992	2006
Food	First	Denmark	Netherlands	Netherlands
	Second	Netherlands	Italy	Finland
	Mean	0.6613837	0.6173996	0.4993243
	Std. Dev.	0.248729	0.2150057	0.2143623
Textiles	First	Netherlands	USA	USA
	Second	USA	Netherlands	Netherlands
	Mean	0.6042541	0.5882222	0.4981595
	Std. Dev.	0.2115653	0.221367	0.2591272
Wood	First	Spain	Spain	Finland
	Second	Denmark	Finland	Spain
	Mean	0.451406	0.5144989	0.4207513
	Std. Dev.	0.2531552	0.2784272	0.2540627
Paper	First	USA	United Kingdom	Finland
	Second	United Kingdom	USA	Austria
	Mean	0.5471339	0.6307027	0.5348344
	Std. Dev.	0.2225478	0.2198874	0.2401655
Fuels	First	United Kingdom	United Kingdom	United Kingdom
	Second	Australia	Australia	Australia
	Mean	0.207211	0.2506919	0.3361084
	Std. Dev.	0.2806901	0.3239166	0.3546466
Chemicals	First	Netherlands	Finland	Netherlands
	Second	Finland	Netherlands	Finland
	Mean	0.520455	0.5049394	0.4661756
	Std. Dev.	0.24939	0.2164211	0.2454609
Plastics	First	Italy	United Kingdom	Italy
	Second	Germany	Italy	Germany
	Mean	0.5359064	0.6240461	0.6341057
	Std. Dev.	0.2635078	0.272627	0.2957324
Minerals	First	Italy	Italy	Italy
	Second	Germany	Germany	Germany
	Mean	0.4664696	0.5004947	0.6112812
	Std. Dev.	0.2264426	0.1954396	0.19651
Metals	First	USA	Italy	Netherlands
	Second	Germany	Netherlands	Finland
	Mean	0.6948542	0.727775	0.6819562
	Std. Dev.	0.2302248	0.1943787	0.2330365
Machinery	First	USA	United Kingdom	United Kingdom
	Second	United Kingdom	USA	Japan
	Mean	0.5691084	0.6763489	0.5734277
	Std. Dev.	0.258623	0.2206757	0.2268817
Electrical	First	Germany	Italy	USA
	Second	Italy	Germany	Finland
	Mean	0.5350925	0.7401513	0.3239626
	Std. Dev.	0.214341	0.1869795	0.300117
Transport	First	USA	Italy	USA
	Second	Italy	USA	Italy
	Mean	0.3675144	0.4397913	0.4181328
	Std. Dev.	0.302568	0.3211532	0.2729201
Recycling	First	United Kingdom	United Kingdom	United Kingdom
	Second	Denmark	Denmark	Denmark
	Mean	0.2593211	0.3395309	0.3583066
	Std. Dev.	0.2761768	0.284549	0.2961837

Source: Author's elaboration based on Griffith, Redding & Reenen (2004, p. 888) using EU KLEMS (2011) data.

Figure 1 – Distance to the frontier in the electrical sector (1979 – 2006)



Source: Author's elaborations based on EU KLEMS (2011).

Finland, except that the country immediately recovers to levels comparable to the US. Throughout the period, Australia also present TFP levels on par with the United States[7].

Inklaar, O'Mahony & Timmer (2005) have showed that ICT-producing industries made the largest contribution to TFP growth both in the US and European countries. After 1995 though, in the US ICT-using industries – mainly associated to wholesale trade, retail trade and financial intermediation – contributed to TFP growth in a quite as large scale as the producing sectors. However, in European countries none of this industries had important contributions to aggregate TFP growth, whilst experiencing a much higher contributions from the non-ICT industries. In contrast, in the US contributions from the latter were very small or even negative.

In Schumpeterian lines, stronger TFP growth in the Electrical sector could be explained in terms of supply efforts captured by research intensity. Indeed the Electrical industries are precisely the ones more intensive in R&D expenditures, followed by Chemicals and Transports. Still, the technology gap grows precisely in the most research intensive sector. However, research

[7] Pilat (2003, p. 51) showed that in 2001 in most OECD countries labour productivity growth also dropped sharply, as output growth in the OECD area slowed down. Still, in some countries such as Australia, labour productivity growth continued to be strong in 2001. In the United States, labour productivity growth immediately picked up in 2002 after a plunge.

intensity levels appears to keep increasing along the time not only in the Electrical industries, but also in Chemicals and Transports, as well as in the Machinery industries and Plastics, although at lower levels.

3.3.3 Econometric investigation

Works differ in their strategies to measure the size of the technology gap. For instance, Fagerberg (1987) uses the level of initial productivity as a proxy for the technology gap in cross-country analysis. On its hand, works such as Amable (1993), Fagerberg & Verspagen (2002) and Griffith, Redding & Reenen (2004) measure the size of the gap as the ratio between a country's productivity and the frontier's productivity. According to both strategies, results have endorsed the notion that technological transfer contributes to closing the gap relative to frontier countries.

Following Griffith, Redding & Reenen's (2004), one way of testing the importance of different factors on technological absorption is endogenizing the technological catch-up parameter using a term of interaction between the variable of interest and the technology gap. The authors use this strategy in testing the effects of research intensity on absorptive capacity. The author's estimations will be reassessed next using the database gathered in the present study, increasing the time span of the original estimations, until 2006. In the sequence, to investigate the effect of industry sophistication on absorptive capacity an interaction term between the size of the gap and the IEXPS index will be regressed against TFP growth. Regressions (3.9) to (3.11) match Griffith, Redding & Reenen's (2004) specifications. On its hand, equations (3.12) and (3.13) include the IEXPS measures.

$$T\hat{F}P_{cit} = \beta_0 + \beta_1 R_{cit-1} + \sigma_1 B + \sigma_2 E + \sigma_3 B * E + u_{cit} \tag{3.9}$$

$$T\hat{F}P_{cit} = \beta_0 + \beta_1 G_{cit-1} + \sigma_1 B + \sigma_2 E + \sigma_3 B * E + u_{cit} \tag{3.10}$$

$$\begin{aligned} T\hat{F}P_{cit} = \beta_0 + \beta_1 R_{cit-1} + \beta_2 R_{cit-1} * G_{cit-1} + \beta_3 G_{cit-1} + \sigma_1 B + \sigma_2 E + \\ \sigma_3 B * E + u_{cit} \end{aligned} \tag{3.11}$$

$$\begin{aligned} T\hat{F}P_{cit} = \beta_0 + \beta_1 R_{cit-1} + \beta_2 R_{cit-1} * G_{cit-1} + \beta_3 G_{cit-1} + \beta_4 N_{cit-1} * G_{cit-1} + \\ \sigma_1 B + \sigma_2 E + \sigma_3 B * E + u_{cit} \end{aligned} \tag{3.12}$$

$$\begin{aligned} T\hat{F}P_{cit} = \beta_0 + \beta_1 R_{cit-1} + \beta_2 R_{cit-1} * G_{cit-1} + \beta_3 G_{cit-1} + \beta_4 N_{cit-1} + \\ \beta_5 N_{cit-1} * G_{cit-1} + \sigma_1 B + \sigma_2 E + \sigma_3 B * E + u_{cit} \end{aligned} \tag{3.13}$$

where R denotes research intensity, G denotes the size of the technology gap and N refers to IEXPS. Table 4 presents the descriptive statistics of the data used in this chapter's estimations, for the period 1979 – 2006. As previously presented, data on IEXPS is available only fro seven countries between 1984 – 2006 due to data availability.

Table 4 – Descriptive statistics

	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
TFP growth	4,004	0.0171	0.1129	-2.3876	1.4008
Technology Gap	4,004	0.5292	0.2741	0.0168	1.0000
Research Intensity	3,527	0.0415	0.0559	0.0000	0.4549
IEXPS	2,093	12.9531	12.4438	0.03716	64.6374

Note: The expoent of the technology gap is reported.

Source: Author's elaboration based on EU KLEMS (2011), ANBERD (2012) and UN Comtrade (2015).

To estimate the regressions 3.9 to 3.13 we follow the methodology laid out in Griffith, Redding & Reenen (2004) in implementing a cross-country-industry panel controlling for unobserved country-industry characteristics affecting TFP growth employing the within estimator. In that case, the unobserved heterogeneity is controlled for by allowing the error term to include a country-industry specific fixed effect a_{ci}. Therefore, a composite error term u_{cit} covers both the country-industry fixed effects and the serially uncorrelated error ε_{cit} (CAMERON; TRIVEDI, 2010).

Moreover, it is necessary to deal with the possible endogeneity arising from the simultaneity between both productivity growth and output growth, and between productivity growth and the lagged technology gap, given that $lnG_{cit-1} = lnTFP_{Fit-1} - lnTFP_{cit-1}$, while $T\hat{F}P_{cit} = lnTFP_{Fit} - lnTFP_{cit-1}$. In the presence of lagged dependent variables, strict exogeneity of the regressors does not hold and the within fixed-effect estimator is no longer consistent. Strictly exogenous variables mean that they are not dependent on neither current nor the past idiosyncratic error e_{it}, which is a quite strong assumption. On its turn, predetermined variables are the ones potentially correlated with past errors. Following Griffith, Redding & Reenen (2004), regressors are assumed to be predetermined and instrumentalized by the first lag. Also IEXPS is likely to be a predetermined regressor, considering that the present structures heavily rely on the prior structure, so that the first lag is also employed.

When estimating Griffith, Redding & Reenen's (2004), results were checked to test for the presence of any influential outlier among countries and industries, as well as test for variations due to the different and expanded time coverage. Firstly, this specification was regressed taking one industry at a time, what revealed the Electrical industry to behave as an outlier, in that excluding this single industry resulted in coefficients closer to those found by Griffith, Redding & Reenen (2004). Indeed, in both Table 3 and Figure 1 it is possible to note that the Electrical industry have been most rapidly diverging after the mid-1990s, mainly due to the incorporation of ICT activities. Once excluding the Electrical sector, results were also sensible to exclusion of the Fuels industry, which produced important changes in bringing results closer to those found in Griffith, Redding & Reenen (2004). Indeed, large spikes in the sector's TFP variation through the years are verified, which are most likely due to measurement errors and large variations in oil prices. The remaining 11 manufacturing sectors didn't produce any significant changes and, therefore, were considered in the final estimations.

As for countries, the same strategy was followed with results being relatively robust to the exclusion of any of the countries in the sample. A regression including only the ones that overlapped Griffith, Redding & Reenen's (2004) sample was carried out, also without resulting in any significant changes. Lastly, the same tests were made considering the time span of both samples, what did not resulted in any significant variations. Should also be mentioned that the present work did not employ skills adjustment and weighted shares os manufacturing employment as in Griffith, Redding & Reenen (2004).

Table 5 present the results of the estimations of Griffith, Redding & Reenen's (2004) specification for testing the two faces o R&D. The research intensity term enters in levels to capture the effect of innovation in pushing the productivity frontier further through the introduction of new technologies. On its hand, to capture the effect of technological transfer from laggard countries, research intensity enters interacted with the size of the gap. According to the author's model, a positive and significant coefficient of the interaction term indicates that the further a country lies behind the frontier the greater the potential for technologies to be transferred through R&D efforts, leading to higher TFP growth rates and faster catch-up.

Table 5 – Griffith's specification, FE (1979 - 2006)

	(1)	(2)	(3)	(4)
Research Intensity, Lag	0.078		0.043	-0.137
	(0.127)		(0.125)	(0.143)
Technology Gap, Lag		0.072***	0.075***	0.066***
		(0.009)	(0.010)	(0.011)
(Research Intensity × Technology Gap), Lag				0.237*
				(0.132)
Constant	0.013***	-0.037***	-0.038***	-0.031***
	(0.004)	(0.007)	(0.008)	(0.008)
Adjusted R^2	0.000	0.033	0.035	0.036
Observations	2902	3267	2902	2902

Standard errors in parentheses
* $p < .10$, ** $p < .05$, *** $p < .01$

Source: Author's elaboration based on EU KLEMS (2011) and ANBERD (2012).

Indeed in column (4) of Table 5 the interaction term is found to be positive and significant at the 10% level, as in Griffith, Redding & Reenen (2004), even though it does not enter as strongly in impacting the rate of TFP growth (it enters with a coefficient of 0.237, while Griffith, Redding & Reenen's (2004) estimates vary between 0.596 and 1.00). As for the technology gap, estimated coefficients are all quite similar to those previously estimated. While Griffith, Redding & Reenen (2004) reported technology gap coefficients that vary from 0.066 to 0.059, the present estimation resulted in a coefficient of 0.066. These results endorse the notion that the greater the technological difference between leaders and followers, the greater the potential of the latter to catch-up faster by absorbing technology.

Nonetheless, the positive and significant coefficient of research intensity reported in Griffith, Redding & Reenen (2004) is no longer verified in the present estimations, as reported in columns (1), (3) and (4). This results suggest that research intensity no longer contributes to expanding the technological frontier, although it still allows for faster incorporation of foreign technologies. This suggests that throughout the year the relationship between R&D and growth have changed. Still, understanding this shifts woulds need a closer exploration of the relationship between research intensity and growth, which extrapolate the scope of the present investigation.

Having this into consideration, the next step is testing the impact of industry sophistication on absorptive capacity. Table 6 report the results of interacting IEXPS with the relative productivity measure. However it should be noted that the sample is significantly smaller than in the previous estimation, since IEXPS were available only for seven countries and 22 years, as previously described. Research intensity remains not significant, while the size of the gap remains highly significant. In column (3) it is verified that IEXPS enters negatively and significantly in explaining convergence in productivity growth. As previously discussed by Hausmann et al. (2011, p. 30) the impact of sophistication on economic growth is associated with a country's income as well as its diversification level. Therefore, lower income countries with less diversified productive structure should face higher opportunities for accelerating TFP growth by incorporating new more complex products exported by diversified high-income countries.

Table 6 – Industry sophistication (IEXPS) and absorptive capacity, FE (1984 - 2006)

	(1)	(2)	(3)
Research Intensity, Lag	0.247	0.239	0.281
	(0.201)	(0.333)	(0.342)
Technology Gap, Lag	0.125***	0.124***	0.105***
	(0.024)	(0.021)	(0.023)
IEXPS, Lag	-0.001	-0.001	-0.002**
	(0.001)	(0.001)	(0.001)
(Research Intensity × L.Technology Gap), Lag		0.009	-0.022
		(0.346)	(0.335)
(IEXPS × Technology Gap), Lag			0.002*
			(0.001)
Constant	-0.064***	-0.064***	-0.051***
	(0.019)	(0.017)	(0.018)
Adjusted R^2	0.078	0.077	0.080
Observations	1393	1393	1393

Standard errors in parentheses
* $p < .10$, ** $p < .05$, *** $p < .01$

Source: Author's elaboration based on EU KLEMS (2011), ANBERD (2012) and UN Comtrade (2015).

Most importantly, when interacted with the size of the technology gap a positive relationship is reported in column (3), significant at the 10% level. This result suggests that the further a country lies behind the frontier and the more oriented towards higher complexity industries, faster it will tend to catch-up. It supports the idea that a more robust basis for learning increases the scope for technology incorporation. Still, the estimated coefficients suggest a small impact of industry sophistication on TFP productivity growth (a variation of a unit in IEXPS would increase TFP in 0.02 percentage points). Lastly, when considering the impact of IEXPS, the role of research intensity on absorptive capacity no longer remains significant.

By expanding Griffith, Redding & Reenen's (2004) investigation and emphasising the role of industry sophistication in closing the productivity gap, it is suggested that a country's composition of production play a role in determining its ability of closing the gap with frontier countries the further it lies from it. The view that the more knowledge embedded in a society, more complex the resulting productive structure suggested by economic complexity approach find support on the concept of absorptive capacity laid down by Cohen & Levinthal (1990). This chapter main contribution is reassessing the work of Griffith, Redding & Reenen (2004) in investigating the factors that influence absorptive capacity. This endorses the central idea of the works of Hausmann, Hwang & Rodrik (2007), Hidalgo et al. (2007), Hidalgo & Hausmann (2009) and Hausmann et al. (2011) that what a country produces have important implication for economic growth and development. An additional finding of this investigations is that the relationship between research intensity and productivity growth seems to have gone through changes in the last decades. Additionally, the creation and incorporation of the ICT sectors in the 1990s introduced a new dynamic to productivity growth, which affect the electrical industries as well as may extrapolate it, to ICT using activities. This in turn may have implications for conditional convergence, which require further investigation.

4 Exploring the determinants of complexity: the role of research intensity

4.1 Introduction

The work of Hausmann, Hwang & Rodrik (2007) acknowledges that development is about the transformation of the productive structure and the learning processes that underly these changes. The authors show that controlling for initial per capita income, human capital and country size, countries with a more sophisticated export basket grow faster. In the same vein as the structural transformation literature, it implies that countries' patterns of specialization geared towards modern activities have important implications for long-term economic growth. In the authors argument, not only growth and development result from structural change, but also specializing in some goods have higher growth prospects than specializing in others.

The authors do not claim any novelty in suggesting that not all activities have the same consequences for development, but rather contribute to this literature by introducing quantitative indexes of product and economic sophistication. While product sophistication measure the productivity levels associated to each product, countries' sophistication is defined in terms of the implied productivity of their export baskets. Increased sophistication therefore, would depend on changing the specialization patterns by incorporating goods of increased sophistication.

What determines sophistication, however, still needs further explaining. Hausmann, Hwang & Rodrik (2007) argue that specialization patterns depend on fundamentals – namely physical and human capital, labour, natural resources and institutional quality – as well as on idiosyncratic elements. The authors' prior investigation have shown that countries' fundamentals account only for part of the variations on sophistication levels across countries. Still, once sophistication is found to be an important predictor of future growth it is crucial to understand where they arise from. This chapter seeks to contribute to further investigating the determinants of sophistication by incorporating visions on technological efforts in increasing sophistication.

4.2 Sophistication and capabilities

The novelty in Hausmann, Hwang & Rodrik's (2007) work is to provide evidence that some traded goods are associated with higher productivity levels, scale effects and learning opportunities characteristic of the modern sectors of the economy by introducing a particular hierarchy of goods with determinate growth implications.

In Hausmann, Hwang & Rodrik's (2007) framework, the rationale underlying product sophistication (PRODY) is that some products are exported by high-income countries, despite its higher wages, because of the characteristics embedded on the exported goods. One important feature concerns the technological content of the product. Nonetheless, other reasons may determine why some products are located in high-income countries. These may refer to infrastructure quality, intellectual property rights, transportation costs, agglomeration externalities and knowledge spillovers, specially in the case of research-intensive activities (FELIPE; KUMAR; ABDON, 2014).

Patterns of economic production differ significantly across countries and regions. Most conventional trade theory attribute such differences to factor endowments and their relative price ratios. These would define a country's comparative advantages and any attempts to reshape the production structure is likely to be inefficient and hamper economic performance. However, alternative arguments emphasize that comparative advantage relies more on a country's capabilities to master and use technologies than on factors endowments (LALL, 2000).

Each product requires a set of capabilities and if a country is able to export such capabilities it means that it has successfully accumulated them. These may refer to human and physical capital, institutions, legal systems and know-how. Traditional theories of comparative advantage may be relevant in cases where technological conditions approximate perfect competition, concerning universally available and easy learning technologies. However, these refer only to one end of the technological spectrum. Technology-intensive activities demands efforts and learning in mastering its tacit elements (LALL, 2000).

To emphasize the role of idiosyncratic elements in determining a country's specialization patterns, Hausmann, Hwang & Rodrik (2007) emphasize the mechanism of "cost discovery" (HAUSMANN; RODRIK, 2003), which is compatible with the notion that specialization patterns do not depend solely on factor endowments. According to it, the process by which an entrepreneur discovers how to produce new goods in the modern sectors generates important knowledge externalities, so that other entrepreneurs can learn and emulate the former. This process would be particularly important for developing economies with undiversified productive structures as means to approach the productivity frontier.

The challenges to expand industrial capabilities, upgrade skills build an innovation and research basis and move into sophisticated products are significant. Schumpeterian literature have long regarded to the process of structural transformation through a series of capability building efforts and diffusing technological progress.

The present study seeks to elaborate on Hausmann, Hwang & Rodrik's (2007) investigation on the determinants of economic sophistication by incorporating the role of technological activities in increasing sophistication. The investigation is conducted in two steps. Firstly, the author's estimation is reproduced using a cross-country panel for a consistent sample of countries over 15 years, starting in 1996. Once the author's prior results are verified in subsection 4.3.2, estimations including research intensity are presented in subsection 4.3.3.

4.3 Empirical investigation

4.3.1 Product and country sophistication

Following Hausmann, Hwang & Rodrik (2007), product and country sophistication indexes were constructed for a 15 year period and a sample of countries as broad as data availability permitted. The resulting indexes are analyzed in the light of the resulting sophistication scores and according to the different technological sectors defined by Lall (2000) [1]. The author's criteria to classify products within a technological sector is based on the nature of the technology, accounting for its required capabilities and technological effort. For instance, medium- and high-technology classes gather high skilled, complex learning and demanding technological activities. On the other end, resource-based and low-technology products are characterized by "easy" technologies in which competitiveness is driven by the availability of natural resources and low wages[2].

Trade data used to calculate PRODY and EXPY come from the United Nations Commodity Trade Statistics Database (UN Comtrade) covering over seven hundred products classified according to the Standard International Trade Classification (SITC), Revision 2, 4-digits[3]. The number of reporting countries varies considerably from year to year. So efforts were made to construct the PRODY measure for a consistent sample of countries that reported trade data over the period of analysis, without losing too many observations[4].

To avoid distortions in the calculation of PRODY, only countries with a population greater or equal to 1,25 million, with a traded value greater or equal than 1 billion and products whose traded value is greater or equal than 10 million were considered. Data on GDP per capita (2011 PPP$) from the World Development Indicators (WDI) was used to calculate the index. After cleaning and deleting missing values, 134 reporting countries were used to construct PRODY. The index, therefore, is measured in 2011 PPP$ and its descriptive statistics are reported in the following table.

1 Lall's (2000) classification comprehend five groups: primary products, resource-based, low-, medium- and high-tech industries. Nonetheless, the PRODY means for resource-based and low-tech products are very close, and since both categories are similar in nature they are considered together under "Low-tech" industries. The same applies for medium- and high-tech activities, being both comprehended under "High-tech" industries.

2 The classification, however, does not imply that some exports remain competitive without technological effort. Regardless of the level of technology, all industrial activities need to be constantly upgraded (LALL, 2000).

3 UN Comtrade (2015) provides annual exports values measured in current US dollars starting from 1962. Some limitations of this database concerns the fact that countries may not report some of its detailed trade, only at higher aggregation levels. They may also not report information in the most recent commodity classification and there is no adjustments for variations in the number of products when converting from more recent to older classifications. Lastly, countries not necessarily report trade statistics every year, hence country coverage vary considerably from time to time.

4 As stressed by Hausmann, Hwang & Rodrik (2007), it is fundamental to use a consistent sample of countries when calculating PRODY, since non-reporting is likely correlated with income. Therefore constructing PRODY for different countries during different years could introduce serious bias into the index.

Table 7 – Descriptive statistics for average PRODY (2011 PPP$) (2008 – 2010)

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
PRODY	408	24,652.63	8,669.14	4,919.674	49,217.20

Source: Author's elaboration based on UN Comtrade (2015) and WDI (2017).

The ten products with the highest and lowest PRODY scores are detailed in Table 8. Using Leamer's (1984) classification[5] as reference, the highest PRODY averages belong to the machinery ($31,045.14) and chemicals ($29,358.59) groups, while the lowest are found in cereals ($20,297.04) and tropical agriculture ($17,111.39). Most of the highest scores are attributed to core products (machinery, chemicals and capital-intensive) and mostly peripheral products (labour-intensive, raw materials, cereals, petroleum, forest, animal and tropical agriculture products) feature amongst the lowest PRODY levels[6].

Table 8 – Products with the highest and Lowest PRODY means (2011 PPP$) (2008 – 2010)

SITC (Rev.2)	Description	PRODY (2008-2010)	Technological class
Top 10 PRODY			
5157	Sulphonamides, sultones and sultams	49,217.20	Low-tech
8851	Watches, watch movements and case	46,625.19	High-tech
3413	Petroleum gases and other gaseous hydrocarbons, nes, liquefied	44,596.34	Primary
5415	Hormones, natural, or reproduce by synthesis, in bulk	43,722.21	High-tech
5831	Polyethylene	42,876.79	High-tech
5416	Glycosides, glands, antisera, vaccines and similar products	42,875.39	High-tech
7928	Aircraft, nes and associated equipment	42,767.83	High-tech
7133	Internal combustion piston engines, marine propulsion	41,654.94	High-tech
0350	Fish, dried, salted or in brine; smoked fish	41,592.50	Low-based
7264	Printing presses	40,829.60	High-tech
Bottom 10 PRODY			
0577	Nuts edible, fresh or dried	8,329.84	Primary
7511	Typewriters; cheque-writing machines	8,248.00	High-tech
2927	Cut flowers and foliage	7,955.08	Primary
2890	Ores and concentrates of precious metals, waste, scrap	7,141.02	Low-tech
2320	Natural rubber latex; natural rubber and gums	7,027.07	Primary
0711	Coffee green, roasted; coffee substitutes containing coffee	7,015.06	Primary
0723	Cocoa butter and paste	6,374.69	Primary
8464	Under-garments, knitted or crocheted of other fibres, not elastic nor rubberized	6,328.01	Low-tech
6116	Leather of other hides or skins	5,767.08	Low-tech
6344	Wood-based panels, nes	4,919.67	Low-tech

Source: Author's elaboration based on UN Comtrade (2015) and WDI (2017).

5 The classification is detailed in Appendix A.

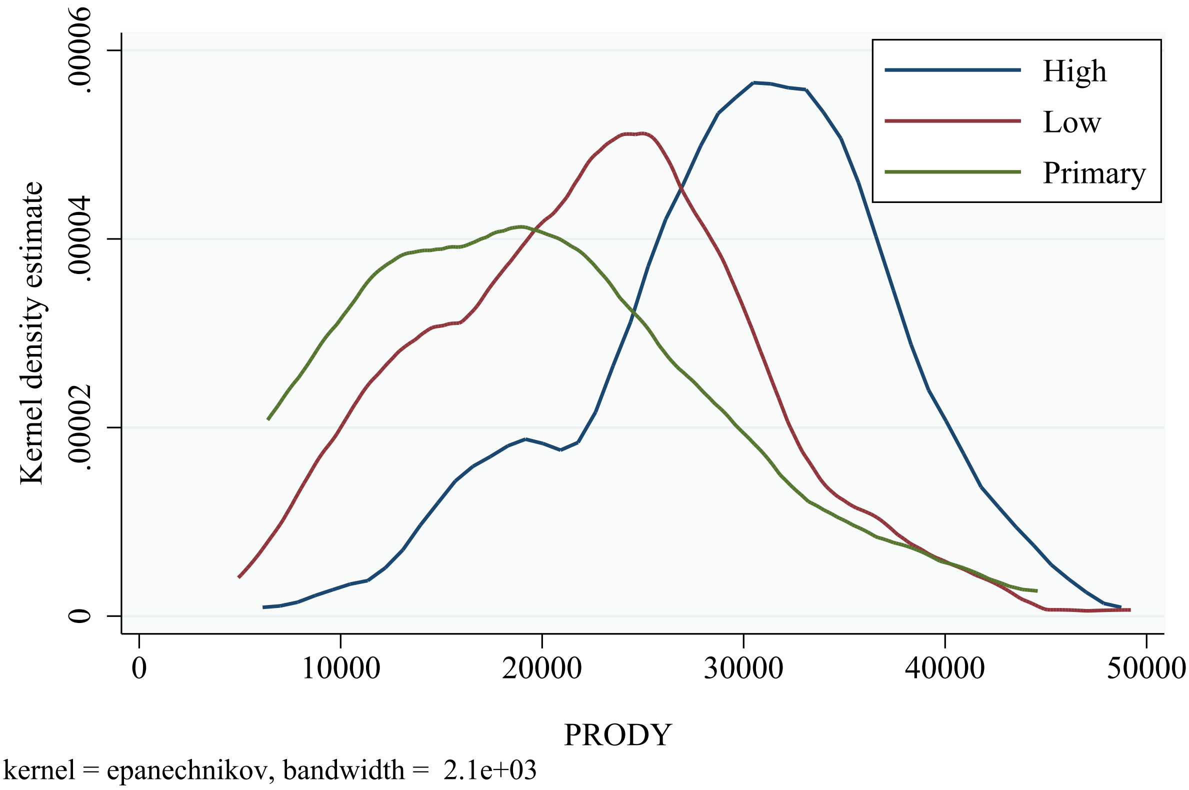
6 Exceptions amongst the highest PRODY values are "dried fish" (animal products) and "petroleum gases" (petroleum), while "typewriters" (machinery) feature amongst the lowest scores

Table 8 also reports the technological intensity of each product. Such classification does not distinguish quality differences within categories, as well as does not indicate the different processes involved in producing a product or show technological upgrading over time within categories (LALL, 2000). Still it provides considerable technological differentiation, shedding light to the technological content embedded in each good. Among the 30% highest PRODY values, most products are classified as high-technology industries, while among the bottom scores, there are mostly low-technology manufactures and primary products.

Still, a few products result in counterintuitive PRODY levels, in that some primary products and low-tech manufactures feature amongst the 10% highest PRODY values. Previous analysis have already shed light into this issue (e.g. Hausmann, Hwang & Rodrik (2007), Reis & Farole (2012), Felipe et al. (2012) and Romero & Britto (2018), among others). These refer to products mostly exported by high income per capita countries. For instance, fuel oils and gases such as "lubricating petroleum oils" and "petroleum gases" are mainly exported by Qatar and European countries, respectively. A few chemicals compounds such as "sulphonamides, sultones and sultams" also score high PRODY values, exported mainly by countries such as Singapore, Ireland, Netherlands, Belgium and Japan. Other products such as "dried fish" also scores high, being exported mostly by Norway, Iceland and Poland.

On the other end, among the 10% lowest PRODY values, figure a few mid or high-technology products. That would be the case of "typewriters" shown in Table 8. Its production is mainly concentrated in China, Malaysia and India. That, in turn, could be a reflection of the fragmentation of production processes, which are located in different places to take advantage of low labor costs, for example. For instance, Lall, Albaladejo & Zhang (2004) note that industries with discrete production processes can experiment greater fragmentation, as well as products with high-value but relatively simple skills could also have its production more easily fragmented.

Figure 2 – Distribution of PRODY values by technology intensity



Note: "High" comprises both medium and high-technology products, whereas "Low" gathers both resource-based products and low-technologies.

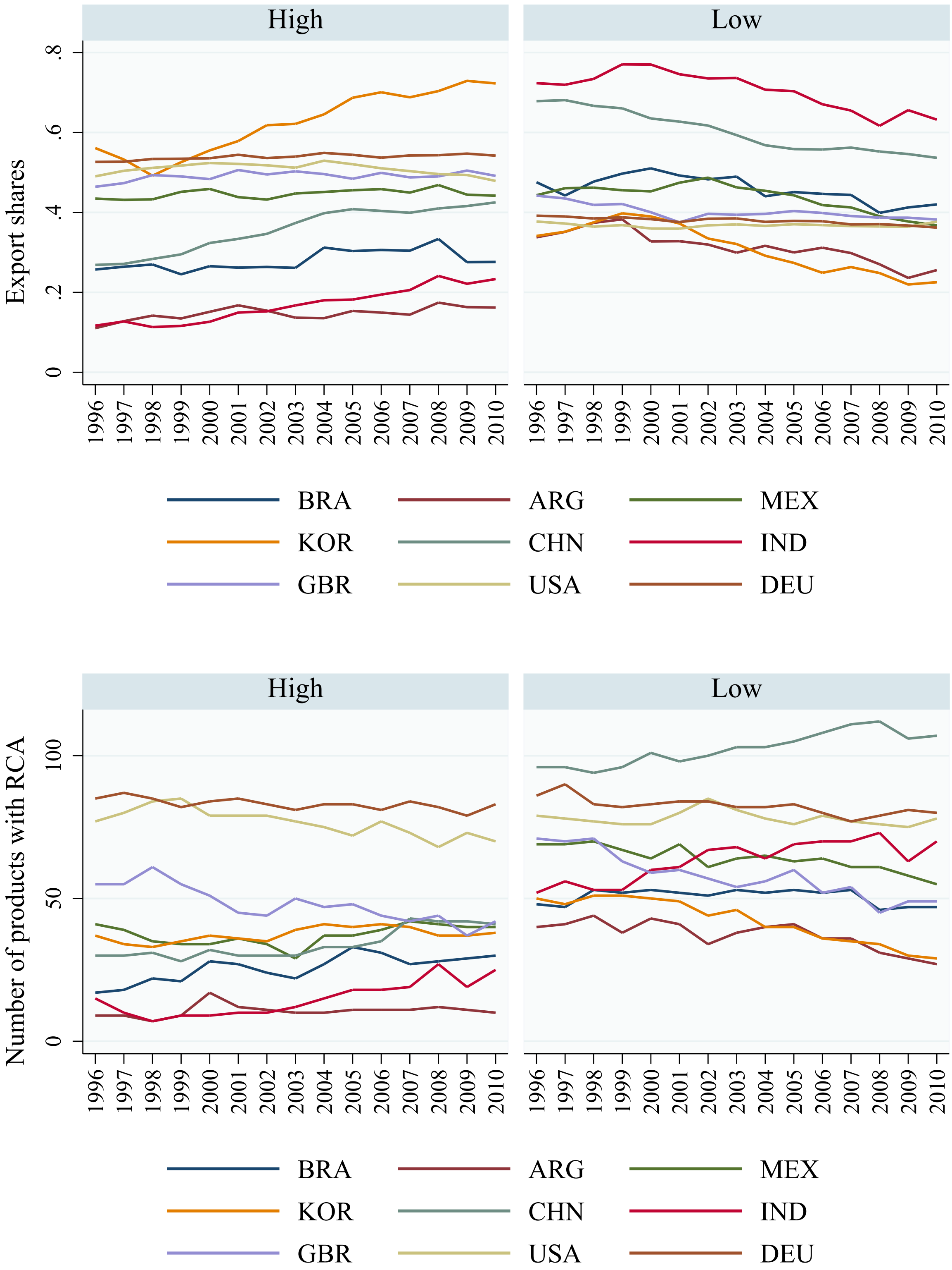
Source: Author's elaborations based on UN Comtrade (2015) and WDI (2017).

Hidalgo & Hausmann (2009) partially solve the problems verified with PRODY when introducing the products and economic complexity calculated by the Method of Reflections. It tries to correct such bias by isolating the effects of income, using instead measures of country diversification (the number of products exported with RCA) and products' ubiquity (the number of exporters with RCA).

The average PRODY from 2008 – 2010 were then used to calculate EXPY for all reporting countries between 1996 to 2010. Country coverage has improved significantly across time, from 64 countries in 1996 to 104 in 2010. The highest EXPY scores refer to economies which heavily rely on resource-based oil exports, including "crude petroleum" and "lubricating petroleum oils", which have relatively high PRODY scores. This shed light to an important limitation of the EXPY measure. Since EXPY is a weighted average of national income levels, countries that are specialized in a few specific commodities with high PRODY scores result in increased sophistication levels. For instance, Qatar, Algeria, Kuwait and Libya altogether exported less products with RCA in 2010 than Norway alone. The group of countries in the second highest EXPY percentile feature Singapore, Japan, Finland, United Kingdom, Sweden, Germany and United States, which exported on average more than a hundred products with RCA in 2010 each.

However, as already noted by Romero & Britto (2018), while export shares of sophisticated goods tend to increase over time, diversification and ubiquity tends to decrease. Therefore EXPY would still be a preferable measure of countries' sophistication. Figure 3 compares the evolution of export shares and number of products exported with RCA by nine selected counties, being three Latin American economies (Brazil, Argentina and Mexico), three East Asian economies (Korea, China and India) and three developed countries (United Kingdom, United States and Germany) in both high- and low-tech industries. It is easy to note that export shares of high-tech products have being increasing, while in low-tech sectors it has been decreasing. Shares in high-tech sectors are highest for the three developed economies and Korea. The number of high-tech products exported with RCA, on its hand, have being decreasing specially in developed economies in both low-tech and high-tech industries. Nonetheless, Asian countries, on its hand have been diversifying in both high-tech and low-tech activities. Latin American countries have also increased the shares of high-tech products as well as diversified in such activities, although not in the same rhythm as the former.

Figure 3 – Export shares and number of products with RCA by technology intensity (1996 – 2010)



Note: "High" comprises both high and medium-tech, while "Low" comprises low-tech and resource-based products acording to the classification of Lall (2000).

Source: Author's elaborations based on UN Comtrade (2015).

To improve comparisons over the years, a consistent sample of 55 countries available for most of the years between 1996 – 2010 is considered. The EXPY descriptive statistics for the sample are reported in Table 9. Holding the income levels associated with each product constant across time, it is possible to note an increase on average in EXPY, as well as sophistication levels across countries grows further apart. Nonetheless, the maximum values vary more than the minimum.

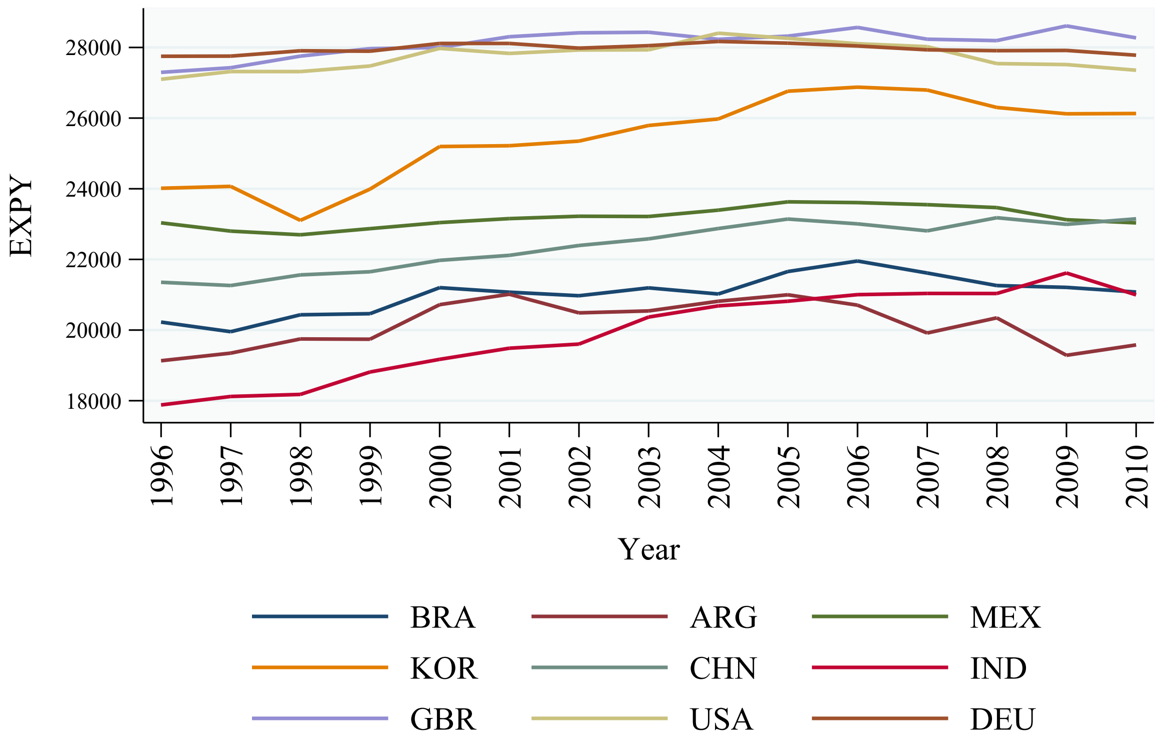
Table 9 – Descriptive statistics for EXPY (2011 PPP$) (1996 – 2010)

Year	Observations	Mean	Std. Dev.	Minimum	Maximum
1996	52	22,956.4	4,107.9	13,518.1	31,992.2
1997	54	22,947.6	4,187.1	13,251.2	32,006.2
1998	54	23,153.7	4,332.3	13,553.2	31,929.9
1999	55	23,223.6	4,296.8	13,436.4	31,916.8
2000	55	23,964.1	4,524.3	13,588.2	37,546.6
2001	55	24,065.5	4,323.4	13,671.1	36,354.5
2002	55	24,092.6	4,343.8	13,898.9	36,594.7
2003	55	24,119.4	4,281.1	12,884.3	35,839.6
2004	55	24,312.3	4,203.1	12,681.9	35,258.6
2005	55	24,611.2	4,281.8	12,747.9	35,771.1
2006	55	24,646.5	4,350.9	12,549.7	35,443.4
2007	54	24,644.2	4,358.4	12,741.6	35,072.7
2008	54	24,738.9	3,950.9	13,237.1	34,565.5
2009	55	24,466.0	4,172.9	13,364.5	33,478.7
2010	55	24,506.7	4,231.3	13,388.4	34,979.1

Source: Author's elaboration based on UN Comtrade (2015).

Figure 4 shows the evolution of sophistication levels for a sample of selected countries. The high income countries, namely United Kingdom (GBR), United States (USA) and Germany (DEU), score EXPY values that differ widely from the developing economies. Still, throughout the years these countries' sophistication increased only marginally. On the other hand, Korea (KOR), India (IND) and China (CHN) registered high increments in their sophistication levels. As depicted in Figure 3, they not only have been experiencing fast economic growth in the referred period, but also their exports shares of high-technology products have been increasing much faster. Along with it, their shares of low-technology exports, have been decreasing.

Figure 4 – EXPY (2011 PPP$) across time for selected countries (1996 – 2010)



Source: Author's elaborations based on UN Comtrade (2015).

While Korea, China and India have been closing the gap with the higher income countries, Latin American economies seemed not to perform as well. Argentina (ARG), Brazil (BRA) and Mexico (MEX) were not able to increase their sophistication levels as rapidly as the Asian economies. Although having higher per capita incomes than China and India, only Mexico achieved an EXPY similar to China. In general, Latin American countries experienced only mild increases. Their ex port share growth in high-technology products vis-a-vis low-tech products is not as expressive either, compared to the figures observed for China, India and Korea.

4.3.2 The role of fundamentals and idiosyncratic elements

As laid out earlier, according to the Hausmann, Hwang & Rodrik's (2007) model, countries engage in activities in the moderns sectors through cost discovery. According to it, specialization patterns depend on a country's fundamentals and its idiosyncratic elements. Among the fundamentals, two key determinants of the cost discovery process are human capital and the size of the labour force. While the former increases the scope of "discoverable" goods, the latter promotes cost discovery through lower wages. Besides, the authors also test the role of institutional quality and land area (a proxy for country size). These are tested in a cross-country estimation controlling for the level of per-capita GDP, which was previously found to be highly correlated with EXPY. Therefore, the specification estimated is defined as:

$$lnEXPY_{it} = \beta_0 + \beta_1 lnY_{it} + \beta_2 lnH_{it} + \beta_3 I + \beta_4 lnP_{it} + \beta_5 lnA_{it} + u_{it} \tag{4.1}$$

where R is research intensity, Y is the product level, H is human capital, I is institutional quality P and A are population size and land area, respectively.

To reassess the authors former results, this equation is re-estimated using cross-national panel data. Human capital is measured as the percentage of total population over 25 years old with complete tertiary education, from Barro & Lee (2013)[7]. Institution quality is measured by the Rule of Law Index, from the World Governance Indicators produced by the World Bank[8](WGI, 2017). Population size and land area are obtained from the World Development Indicators (WDI, 2017), same as the GDP per capital in Purchase Power Parities (PPP) constant 2011 prices in international units. To obtain a balanced panel set, a consistent sample of countries was built by removing the gaps and checking for outliers. As a result, 47 countries comprise the final sample, smaller than the one employed by Hausmann, Hwang & Rodrik (2007). Data covers the period between 1996 and 2010.

Since it is expected to be country's unobserved characteristics not captured by the model, the within estimator is employed. In that case, the error term includes the countries' specific fixed-effects α_i, correcting for the characteristics that are invariant through time. The error term is, therefore expressed by $u_{it} = \alpha_i + \varepsilon_{it}$, where ε_{it} is a serially uncorrelated error. By eliminating the effect of invariant characteristics in time using the individual means, consistency of the coefficients for the time-varying regressors can be achieved, allowing them to be correlated with the non-observed time invariant characteristics, but not with the idiosyncratic term of the composite error. Also, the estimators assume homoscedasticity, which is most likely violated in panel data. Therefore, a cluster-robust estimate of the covariance-variance matrix is employed in estimating the standard errors (CAMERON; TRIVEDI, 2010). Table 10 report the estimations of regressing Equation 4.1, whereby variables are introduced one at a time.

[7] Data is available from 1950 to 2010 in 5-year intervals. To obtain a full time series, linearly interpolation was employed.

[8] The Rule of law index aims at capturing the perceptions of the extent to which agents have confidence in and abide by the rules of society, particularly the quality of contract enforcement, property rights, the police, and the courts. Data was not available for 1997, 1999 and 2001, therefore linear interpolation was used to input data for these years.

Table 10 – Determinants of sophistication, FE (1996 – 2010)

Dependent variable: Log EXPY	(1)	(2)	(3)	(4)
Log GDP per capita, PPP (2011)	0.145***	0.106***	0.107***	0.084***
	(0.029)	(0.030)	(0.029)	(0.025)
Log Human capital		0.049**	0.050**	0.034
		(0.023)	(0.024)	(0.028)
Rule of Law			-0.032	-0.020
			(0.024)	(0.023)
Log Population, total				0.179*
				(0.109)
Log Land area (sq. km)				-0.064
				(0.539)
Constant	8.642***	8.916***	8.926***	6.929
	(0.293)	(0.277)	(0.267)	(6.127)
Adjusted R^2	0.257	0.285	0.296	0.320
Observations	720	720	720	716

Standard errors in parentheses
* $p < .10$, ** $p < .05$, *** $p < .01$

Source: Author's elaboration based on WDI (2017), WGI (2017) and Barro & Lee (2013).

The results follow the authors findings, although the present estimation result in smaller coefficients, what should take into account the different samples employed, as well that time invariant country characteristics are controlled for. For instance, the estimated coefficient of per-capita GDP varies from 0.35 to 0.15. Significance levels, in turn, still point to a strong correlation between income per capita and EXPY. Human capital is also find to positively impact sophistication levels when controlling fo per-capita GDP, although the estimated coefficient is considerably smaller (the panel estimation resulted in a coefficient of 0.05 in column (2), while Hausmann, Hwang & Rodrik's (2007) estimation resulted in a coefficient of 0.28). Despite that, human capital is found to exert a positive effect on EXPY which is put by Hausmann, Hwang & Rodrik (2007) in terms of increasing the scope for cost discovery. Technology-gap perspectives, on their hand, stress the role of human capital in stimulating innovations and rapidly incorporating new products allowing for conditional converge across countries.

Institutional quality once again is found not to be associated with EXPY when controlling for per-capita GDP in column (3). Also land area, introduced as a measure of country size, shows not have any relation with EXPY in column (4). Human capital no longer remains significant with the inclusion of population size, which was found to produce a significant impact on EXPY when controlling for the other factors. Although it is found to be significant only at the 10% level, it resulted in a large coefficient of 0.18, compared to 0.09 found by Hausmann, Hwang & Rodrik (2007), markedly being twice as large as the estimated impact of GDP per capita in the panel set. In other words, a variation of 1% in population size would increase EXPY in 0.18 percentage points, which is a quite large variation. This result might concern the influence of scale effects affecting sophistication levels. Hausmann, Hwang & Rodrik (2007) suggest that population size could promote cost-discovery by lowering the wages, so countries might face cost advantages in the production of more sophisticated goods. Nonetheless, as being noted earlier, that is usually a characteristic of less technology-intensive activities. In fact, as will be presented next, the population size no longer remains significant when accounting for the role of technological activities in determining sophistication levels.

The empirical investigation on the determinants of sophistication carried out by Hausmann, Hwang & Rodrik (2007) provided only an initial approximation of the covariates of EXPY. When reproducing these tests in a panel estimation over 15 years, results have overall held despite the different time period, sample composition and estimation strategy. In line with Hausmann, Hwang & Rodrik (2007), results are acknowledged to account only for part of the determinants of sophistication. The large portion of variations in EXPY left unexplained are suggested to lay on the idiosyncratic elements underlaying the emergence of new successful industries. The next section aims to develop on this idea, by introducing the role of technological activities in shaping a country's sophistication.

4.3.3 Testing the role of technological efforts

The suspicion that differences across countries have something to do with technology have been around for decades. According to the Schumpeterian literature discussed in chapter 2, technical change takes place mainly through technological efforts. Within this framework, the capabilities approach suggests that many indigenous factors influence the ability of promoting technological change, as expressed in a number of indicators of technological activity, such as patents, R&D, education, telephone lines, internet access, scientific publications and medium and high-tech exports. Nonetheless, these are all find to be strongly correlated with each other, as well as with economic performance and growth (ARCHIBUGI; COCO, 2005). At aggregate levels, the impact of research intensity on technical progress is at the core of Schumpeterian growth models, capturing the aggregate effort in promoting learning and generating knowledge, leading to higher technical progress and productivity growth by either absorbing foreign technology or incorporating new products (ROMER, 1990; AGHION; HOWITT, 1992; HA; HOWITT, 2007).

To investigate the role of technological activities in determining a country's sophistication, research intensity is incorporated in the equation formerly estimated. A country's efforts in learning and generating technical progress should impact sophistication, by increasing the scope for the incorporation of more dynamic sectors of higher demand growth and greater opportunities for technical change. To that end the following equation is to be estimated.

$$lnEXPY_{it} = \beta_0 + \beta_1 lnR_{it} + \beta_2 lnY_{it} + \beta_3 lnH_{it} + \beta_4 I + \beta_5 lnP_{it} + \beta_6 lnA_{it} + u_{it} \tag{4.2}$$

where R is research intensity, Y is the product level, H is human capital, I is institutional quality P and A are population size and land area, respectively.

Research intensity is calculated as the ratio between patent counts and the number os persons engaged in production. Data on the latter is obtained from the Penn World Table (PWT) version 9.0 (FEENSTRA; INKLAAR; TIMMER, 2015). Data on patents for each country and year were collected from the United States Patent and Trademark Office (USPTO)[9].

Table 11 – Research intensity and the determinants of EXPY, FE (1996 – 2010)

	(1)	(2)	(3)	(4)	(5)
Log Research intensity	0.043***	0.024***	0.025***	0.024***	0.022***
	(0.008)	(0.008)	(0.007)	(0.007)	(0.006)
Log GDP per capita, PPP (2011)		0.100***	0.055*	0.058*	0.042
		(0.031)	(0.030)	(0.029)	(0.026)
Log Human capital			0.052**	0.053**	0.039
			(0.024)	(0.024)	(0.028)
Rule of Law				-0.027	-0.018
				(0.023)	(0.022)
Log Population, total					0.151
					(0.102)
Log Land area (sq. km)					-0.013
					(0.492)
Constant	9.954***	9.020***	9.336***	9.330***	7.110
	(0.022)	(0.303)	(0.272)	(0.267)	(5.613)
Adjusted R^2	0.223	0.299	0.332	0.339	0.357
Observations	720	720	720	720	716

Standard errors in parentheses
* $p < .10$, ** $p < .05$, *** $p < .01$

Source: Author's elaboration based on WDI (2017), WGI (2017), USPTO (2015), Feenstra, Inklaar & Timmer (2015) and Barro & Lee (2013).

Research intensity is found to be strongly correlated to EXPY in column (1) without controlling for per-capita GDP. When adding the latter in column (2), it enters positively and significantly, as well as research intensity remains significant at 1%. The effect of research intensity on EXPY is quite smaller though. While a variation of one percentage point in the latter increases sophistication by 0.1 percentage point, the former increases it by only 0.02%. Human capital enters the equation significantly only at the 5% level, although with a higher impact on EXPY than research intensity. Institutional quality remains not significant in column (4). Finally, when accounting for population size and land area, the former, which have previously showed to exert a high impact on EXPY, is no longer significant when testing the role of technological activities. Lastly, the significance of per-capita GDP weakens with the inclusion of the regressors, highlighting the role attributed to research intensity.

Indeed the tests suggested that differences in EXPY have something to do with a country's technological activities. These are the ones that increase the ability to master and use the tacit elements of technology, as well as to shift the composition of production towards higher value added activities. Lastly, Hausmann, Hwang & Rodrik (2007) found a strong correlation between

9 United Sates patenting activity has been used extensively in several analyses of global scope, taking the importance and size of the country's technological market. Its systematic application also makes it suitable for comparisons across countries and over time.

income growth and sophistication. Although these are partly related by construction, the authors claim that this relationship is not merely a mechanic one. The sophistication of a country's export basket is shown to exert an independent impact on economic growth and to work as a good predictor of future growth. Along the Schumpeterian literature, research intensity is also find to generate economic and productivity growth by increasing technological progress (FAGERBERG, 1994).

The contribution of this investigation is, therefore, to point to an additional factor explaining the variations in economic sophistication. The role of national technological activities stressed in the Schumpeterian literature is compatible with the notion that idiosyncratic factors play an important role in determining a countries specialization patterns, as well as support the idea that not all products carry the same consequences for development.The debate on the importance of specialization patterns for long term growth, restored by the new empirical measures introduced by Hausmann, Hwang & Rodrik (2007), can, therefore, be complemented with the Schumpeterian insights on technical change and growth in further understanding technical change from a country and product sophistication perspectives.

Final considerations

The present dissertation aimed to address the issue of economic development and structural change in the light of the empirical contributions provided by the economic complexity approach, emphasising sources of sophistication increases through learning and capabilities accumulation. This approach was found to provide strong support for a series of views emphasising the role of specialization patterns. These point to the need of transforming the production set of developing countries by incorporating more complex products. These would be the ones with higher knowledge and associated with better economic performance. A number of studies so far have showed that the complexity measures are positively correlated with income growth, as well as productivity growth. Sophistication would also be positively correlated with the probability of developing new products, according to a consistent path of increasing complexity in the development process.

Still a lot remained unexplored in terms of the factors leading to increasing sophistication levels. The present study conducted efforts in this direction regarding two core insights of the Schumpeterian: technological absorption and national technological activities. It is argued that both insights are at some degree related to sophistication measures, providing two main contributions to understanding their role in increasing sophistication. Firstly, industry sophistication may affect absorptive capacity the further a country lies behind the productivity frontier. Backward economies with specialization patterns geared towards more sophisticated industries would more easily incorporate new knowledge necessary to diversify into new activities further increasing sophistication. Secondly, national technological activities measured by research intensity was found to positively affect sophistication levels, accounting for part of the idiosyncratic elements in shaping a country's composition of production.

More specifically, chapter 3 firstly reassess the work of Griffith, Redding & Reenen (2004) to investigate the role of research intensity on absorptive capacity. A first issue that appears when estimating the authors model is the finding that the relationship between research intensity, the size of the gap and TFP growth appears to have changed throughout the years, since Griffith, Redding & Reenen's (2004) estimations were carried out. In the re-estimation of the model, research intensity appeared to no longer contribute to operated in expanding the technological frontier. In other words, the innovative role of research intensity was not verified. It affected productivity growth only through absorptive capacity, contributing to movements inside the technological frontier.

Another important observation brought into light by this investigation when calculating countries' distance to the technological frontier is the fact that after the mid-1990s ICT technologies introduced serious structural changes in the catching-up patterns and productivity growth.

While the United States productivity entered a strong path of growth, most other countries fell behind. A vast literature from the early 2000s address this issues within a growth accounting framework, suggesting that not ICT-producing sectors, but also ICT-using activities benefited from the introduction of such technologies. In fact, the resulting relative productivity levels calculated for the period after the 1990s suggested that in some sectors divergence seemed to have taken place, while until the mid-nineties some degree of convergence appeared to be underway, as showed by Griffith, Redding & Reenen (2004).

Despite that, a role was attributed to industry sophistication in increasing absorptive capacity and bringing less diversified countries closer to the frontiers. It also appeared to exert an independent effect on TFP growth in the sense that as countries become more diversified (reflecting in higher IEXPS) the effect of industry sophistication in increasing productivity levels diminishes. In fact, it has already been suggested that diversification is more bounded by the availability of capabilities at early stages of developments. As countries diversify, adding jumping to another product has lower effects on overall productivity. These results however, are rather fragile to inclusion of the Electrical industry. It is possible that alternative methods more adequate to deal with heterogeneous panels produce more robust results, as well as further exploring the sources of productivity divergences across industries.

Lastly, testing the covariates of EXPY in the light of the model laid out by Hausmann, Hwang & Rodrik (2007) provided some insights about sophistication. Reproducing the authors estimation in a panel regression correcting for countries unobserved characteristics, a positive relationship between per-capita GDP, human capital and population size is once again verified. In sequence, as means to account for part of the unexplained factor determining sophistication levels, which were likely related to country's idiosyncratic elements, a step further was taken by accounting for a positive relationship between national technological activities and sophistication. Hence, increasing sophistication and the resulting composition of production would depend on efforts for learning and capability building.

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Appendix

APPENDIX A – Leamer Groups

Table 12 – Products by Leamer's Groups

SITC Rev.2	Description	Leamer Group
00	Live animals chiefly for food	Animal Products
01	Meat and preparations	Animal Products
02	Dairy products and birds' eggs	Animal Products
03	Fish, crustacean and molluscs, and preparations thereof	Animal Products
04	Cereals and cereal preparations	Cereals
05	Vegetables and fruit	Tropical Agriculture
06	Sugar, sugar preparations and honey	Tropical Agriculture
07	Coffee, tea, cocoa, spices, and manufactures thereof	Tropical Agriculture
08	Feeding stuff for animals (not including unmilled cereals)	Cereals
09	Miscellaneous edible products and preparations	Cereals
11	Beverages	Tropical Agriculture
12	Tobacco and tobacco manufactures	Cereals
21	Hides, skins and furskins, raw	Animal Products
22	Oil seeds and oleaginous fruit	Cereals
23	Crude rubber (including synthetic and reclaimed)	Tropical Agriculture
24	Cork and wood	Forest Products
25	Pulp and waste paper	Forest Products
26	Textile fibres (not wool tops) and their wastes (not in yarn)	Cereals
27	Crude fertilizer and crude minerals	Raw Materials
28	Metalliferous ores and metal scrap	Raw Materials
29	Crude animal and vegetable materials, nes	Animal Products
32	Coal, coke and briquettes	Raw Materials
33	Petroleum, petroleum products and related materials	Petroleum
34	Gas, natural and manufactured	Raw Materials
35	Electric current	Raw Materials
41	Animal oils and fats	Cereals
42	Fixed vegetable oils and fats	Cereals
43	Animal and vegetable oils and fats, processed, and waxes	Animal Products
51	Organic chemicals	Chemicals
52	Inorganic chemicals	Chemicals
53	Dyeing, tanning and colouring materials	Chemicals
54	Medicinal and pharmaceutical products	Chemicals
55	Oils and perfume materials; toilet and cleansing preparations	Chemicals
56	Fertilizers, manufactured	Chemicals
57	Explosives and pyrotechnic products	Chemicals
58	Artificial resins and plastic materials, and cellulose esters etc	Chemicals
59	Chemical materials and products, nes	Chemicals
61	Leather, leather manufactures, nes, and dressed furskins	Capital Intensive
62	Rubber manufactures, nes	Capital Intensive
63	Cork and wood, cork manufactures	Forest Products
64	Paper, paperboard, and articles of pulp, of paper or of paperboard	Forest Products
65	Textile yarn, fabrics, made-up articles, nes, and related products	Capital Intensive
66	Non-metallic mineral manufactures, nes	Labour Intensive
67*	Iron and steel	Capital Intensive
68	Non-ferrous metals	Raw Materials
69*	Manufactures of metals, nes	Capital Intensive

(*continued*)

(*continue*)

SITC Rev.2	Description	Leamer Group
71	Power generating machinery and equipment	Machinery
72	Machinery specialized for particular industries	Machinery
73	Metalworking machinery	Machinery
74	General industrial machinery and equipment, nes, and parts of, nes	Machinery
75	Office machines and automatic data processing equipment	Machinery
76	Telecommunications, sound recording and reproducing equipment	Machinery
77	Electric machinery, apparatus and appliances, nes, and parts, nes	Machinery
78	Road vehicles	Machinery
79	Other transport equipment	Machinery
81	Sanitary, plumbing, heating, lighting fixtures and fittings, nes	Capital Intensive
82	Furniture and parts thereof	Labour Intensive
83	Travel goods, handbags and similar containers	Labour Intensive
84	Articles of apparel and clothing accessories	Labour Intensive
85	Footwear	Labour Intensive
87	Professional, scientific, controlling instruments, apparatus, nes	Machinery
88	Photographic equipment and supplies, optical goods; watches, etc	Machinery
89	Miscellaneous manufactured articles, nes	Labour Intensive
93	Special transactions, commodity not classified according to class	Labour Intensive
94	Animals, live, nes, (including zoo animals, pets, insects, etc)	Animal Products
95	Armoured fighting vehicles, war firearms, ammunition, parts, nes	Machinery
96	Coin (other than gold coin), not being legal tender	Labour Intensive
97	Gold, non-monetary (excluding gold ores and concentrates)	Raw Materials

Note: *Disaggregated in "Metals" by Felipe, Kumar & Abdon (2014).

Source: Adapted from Felipe, Kumar & Abdon (2014).

APPENDIX B – Correspondence between ISIC Rev.2 and Rev.3

At this level of aggregation it is quite straightforward to make both Rev.2 and Rev.3 of ISIC compatible without any significant information loss. The correspondence used in the present work can be found in Romero (2015).

Table 13 – Correspondence between ISIC Rev.2 and Rev.3

ISIC Rev.2	ISIC Rev.3	Description (ISIC Rev.3)
1	AtB	Agriculture, hunting, forestry and fishing
2	C	Mining and quarrying
3	D	Total manufacturing
4	E	Electricity, gas and water supply
33	20	Wood and products of wood and cork
353+354	23	Coke, refined petroleum products and nuclear fuel
351+352	24	Chemicals and chemical products
355+356	25	Rubber and plastics products
36	26	Other non-metallic mineral products
382*	29	Machinery, nec
31	15t16	Food products, beverages and tobacco
32	17t19	Textiles, textile products, leather and footwear
34	21t22	Pulp, paper, paper products, printing and publishing
37	27t28	Basic metals and fabricated metal products
381	27t28	Basic metals and fabricated metal products
383	30t33	Electrical and optical equipment
385	30t33	Electrical and optical equipment
384	34t35	Transport equipment
39	36t37	Manufacturing nec; recycling

Source: Adapted from Romero (2015, p. 229).