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A study about the relationship between intellectual property rights (IPR) and growth: a theoretical analysis and an empirical test

Doctoral Thesis of

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Biographical Note

Mónica Isabel Lopes Azevedo was born on the 24th of May 1988, in Escariz, Arouca, Portugal.

In 2006 she was admitted in the undergraduate course of Economics at Faculty of Economics of the University of Porto and she graduated in 2009, with the final classification of 16 out of 20.

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In September 2009 she began the PhD program in Economics, at Faculty of Economics of the University of Porto. In July 2011 she concluded the curricular part of the program with a classification of 16.

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She participated in some conferences and seminars. Namely, she presented the essay "Endogenous growth and intellectual property rights: a north-south modelling proposal" in the 7th Annual Meeting of the Portuguese Economic Journal, Covilhã, 2013.

She was a referee of two articles for the *Economic Modelling*.

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[1] CEF.UP - Centro de Economia e Finanças da Universidade do Porto - was created in 2009 and it is hosted by *Faculdade de Economia - Universidade do Porto* since its creation. Since October 2011, it is also hosted by the Porto Business School. This research center in Economics and Finance is supported by the *Fundação para a Ciência e a Tecnologia*, Portugal.

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To my Dad

Abstract

This thesis studies the relationship between Intellectual Property Rights (IPR) and economic growth. Although literature on this matter has increased over the last decade, the direct effect of IPR on growth is still a controversial issue. Thus, this effect is certainly not completely understood.

IPR have a dual role on economic growth and several works have been proposing arguments for and against IPR. Given this ambiguity, we propose a comprehensive and deep overview of the existing theoretical and empirical literature on the subject, systematizing the main conclusions related to the relationship between IPR and endogenous growth, and we try to uncover the main gaps in the current research agenda.

Secondly, we develop a general equilibrium endogenous growth model which emphasizes the IPR effects on growth, in a scenario of North-South technological knowledge diffusion. In line with the literature, we introduce an IPR parameter which makes imitation more difficult. We find that, in steady state, the increases in IPR protection result in decreases in the growth rate.

Afterwards, we examine the effect of IPR on economic growth. Using a panel dataset and a two-stage estimation procedure, it shows that IPR protection affects economic growth in robust terms. In order to avoid some bias caused by the IPR measure, we obtain the IPR value residually and then we verify that countries with higher levels of IPR protection have lower economic growth rates. Hence, the results confirm a negative impact of IPR protection on economic growth.

In addition, we study the IPR effect on economic growth, in the presence of population ageing. Besides, we analyse this relationship in a framework where there is a health care sector. We conclude that, by introducing population ageing in the model, there is no impact in the sign of the IPR effect on economic growth. However, it affects positively the steady state growth rate. Finally, under some conditions, the presence of the health care sector also increases the steady state growth rate.

Keywords: North-South; R&D; Endogenous Economic Growth; Intellectual Property Rights; Ageing; Innovation; Imitation; Health Care.

JEL classification: C8, I15, J10, O3, O33, O34, O4, O41, O43.

Resumo

Esta tese estuda a relação entre os Direitos de Propriedade Intelectual (DPI) e o crescimento económico. Embora a literatura sobre este assunto tenha aumentado na última década, o efeito direto da proteção dos DPI no crescimento é ainda um assunto controverso. Assim, este efeito não é totalmente conhecido.

Os DPI têm um duplo papel no crescimento económico e têm sido propostos argumentos contra e a favor dos DPI. Tendo em conta esta ambiguidade, nós propomos uma revisão da literatura teórica e empírica existente sobre o assunto, sistematizando as principais conclusões acerca da relação entre os DPI e o crescimento endógeno, e tentamos indicar as principais lacunas aí presentes.

Em segundo lugar, nós desenvolvemos um modelo de crescimento endógeno de equilíbrio geral que enfatiza os efeitos dos DPI no crescimento, num cenário de difusão do conhecimento tecnológico entre o Norte e o Sul. Tendo em conta a literatura, nós introduzimos um parâmetro de DPI que torna a imitação mais difícil e descobrimos que, no estado estacionário, os aumentos na proteção dos DPI resultam em decréscimos na taxa de crescimento.

Depois, usando um painel de dados e um procedimento de estimação em duas fases, mostramos que a proteção dos DPI afeta o crescimento económico de forma robusta. Para evitar o possível enviesamento causado pela medida dos DPI, nós obtemos residualmente o valor dos mesmos e, posteriormente, verificamos que os níveis elevados de proteção dos DPI estão associados a taxas de crescimento económico reduzidas. Deste modo, os resultados confirmam um impacto negativo da proteção dos DPI no crescimento económico.

Por fim, nós estudamos o efeito dos DPI no crescimento económico tendo em conta o envelhecimento da população e a existência do setor de cuidados de saúde. Nós concluímos que, ao introduzir o envelhecimento da população no modelo, não há impacto no sinal do efeito dos DPI no crescimento económico. No entanto, afecta positivamente a taxa de crescimento do estado estacionário. Sob algumas condições, a presença do sector de cuidados de saúde também pode aumentar a taxa de crescimento do estado estacionário.

Palavras-chave: Norte-Sul; I&D; Crescimento Económico Endógeno; Direitos de Propriedade Intelectual; Envelhecimento; Inovação; Imitação; Cuidados de Saúde.

Classificação JEL: C8, I15, J10, O3, O33, O34, O4, O41, O43.

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Chapter 1

Introduction

Intellectual Property Rights (henceforward IPR) have been identified as an important topic in economics. Therefore, they have gained increasing attention in the academic research. It is common to find references in the literature to IPR and/or to the potential relationship between IPR and major economic variables. Nevertheless, we can affirm that only over the last decade the literature on this subject observed a massive growth. Moreover, if we refer to IPR in the specific context of economic growth, we verify that the literature is not much and it has significantly increased over the last decade (Azevedo *et al.*, forthcoming). However, the relationship between IPR and economic growth has not been fully apprehended, and there is no consensus about both the signal and the causality beneath this relationship.

The purpose of this thesis is to give a significant contribution for the study of the relationship between IPR and growth. In order to achieve this major goal, we present four essays on this subject. The first essay presents an overview of the existing literature (both theoretical and empirical) on this topic. In the second one, a model which allows us to analyse the sign of the IPR effect on growth is developed. The third essay tests empirically the model proposed in essay two, developing a deep analysis on the relationship under study. Finally, in the last essay, we propose an extension of the model offered in the second essay, by introducing ageing population and health care sector in the model. The thesis includes six chapters. After these introductory remarks, which give a global summary of the document, the four essays are presented and a final chapter concludes and presents further research paths.

Chapter 2 presents a comprehensive and deep overview of the existing theoretical and empirical literature on the relationship between IPR and economic growth. After a brief review on the IPR origins namely in the economic context, we study the main theoretical contributions on this same relationship, also enlarging the scope in terms of economic performance to innovation and/or welfare,[2] and we systematize the main conclusions. The conclusions about this relationship significantly differ among the analysed studies. The differences are not only in terms of the sign of the IPR effect on growth (innovation or welfare), but also in terms of the used IPR concept. From our deep analysis of all these studies, we claim that the differences on the impact of IPR on economic growth are justified not only by the differences in the concept of IPR, but are also associated to the fact that, namely in what concerns empirical studies, these use distinct samples and methodologies.

In Chapter 3, we continue the analysis of the theoretical literature on IPR and economic growth, but now specifically focused on the theoretical framework of endogenous growth. Specifically, this chapter analysis the sign of the relationship between IPR and economic growth. We develop here a two-country theoretical endogenous growth model in the presence of technological knowledge diffusion. Based on Connolly and Valderrama (2005) and Afonso (2012), we verify the behaviour of the growth rate when there are changes in the level of IPR protection. Relatively to the cited papers, we certainly add a much higher focus on IPR. We not only have into consideration the existence of IPR but we also attribute to IPR the central role in the analysis, that is, we consider IPR as the key element in study. We conclude that IPR assume a relevant role in the model and that the growth rate is, in fact, affected by this presence.

Chapter 4 studies empirically the relationship between IPR and economic growth. Thus, we intend to determine the IPR value as well as to check the explanatory power of the model presented in the Chapter 3. Additionally, we want to provide a study about

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[2] We do not study only the IPR effect on growth because the existing literature on IPR and endogenous growth models was rather scarce in what regards investigation of the direct relationship.

the direct effect of IPR on economic growth. In this sense, we use an estimation of the model developed in the previous chapter and we add some control variables in order to test the robustness of the model. Moreover, we compute in residual terms the IPR value associated to the estimated growth rate, which allow us to reduce the bias that exists in the literature due to the fact that IPR are measured in very distinct ways.

In Chapter 5, the model developed in the Chapter 2 is extended by introducing ageing population and health care sector in the analysis. The central aim is to verify how the results obtained in the Chapter 2 change when we introduce this phenomenon and we find that the sign of the variation in growth rate due to a change in the IPR level is not affected. However, we state that growth rate is positively affected by population ageing.

Chapter 6 comprise the main conclusions of this thesis as well as some suggestions for future research.

Chapter 2

Intellectual Property Rights and Endogenous Economic Growth: uncovering the main gaps in the research agenda

A preliminary version of this chapter was published in 2012 as 'Intellectual property rights and endogenous economic growth – uncovering the main gaps in the research agenda', in *Technological Change*, Aurora A. C. Teixeira (editor), ISBN: 978-953-51-0509-1, InTech, DOI: 10.5772/37768, chapter 3, pp. 45-64.

2.1. Overview

Intellectual Property Rights (IPR) are "the rights to use and sell knowledge and inventions" (Greenhalgh and Rogers, 2007: 541), with the aim of guaranteeing adequate returns for innovators and creators. There are different types of intellectual property protection (Granstrand, 2005): old types such as patents, trade secrets, copyrights, trademarks and design rights, and new forms such as breeding rights and database rights. Nonetheless, patents are commonly considered as the most important and representative IPR (*e.g.*, Besen and Raskind, 1991).

IPR have a long legal and economic history, since the idea of intellectual property was already present in ancient cultures such as Babylonia, Egypt, Greece and the Roman Empire. Mokyr (2009) discusses the relevance of the late 19th century, when political events created a system which supported an executive that was sufficiently well-organised to create a "rule of law" and respect private property rights. This argument emerges, in part, in the context of an Industrial Revolution marked by important technological improvements, whereby IPR began gradually to be accorded more respect.

Despite this long history, only recently has IPR come to play a central role in debates concerning economic policy, being a stimulus for innovation through monopoly power (Menell, 1999). This change, related to the pro-patent era, only emerged in the 20th century – first in the USA and then globally in the world. Beneath this profound transformation lay a "deeper, more broad-based and much slower flow of events towards a more information- (knowledge-) intensive and innovation-based economy" (Granstrand, 2005: 266). Therefore, in this period, knowledge and information assumed an important role in economics, which implied important changes in policy-making both in developed and developing countries.

The relationship between IPR, technological change and economic growth is ambiguous (*e.g.*, Horii and Iwaisako, 2007; Harayuma, 2009; Panagopoulos, 2009). Although knowledge and innovation are crucial for economic growth (*e.g.*, Romer, 1990; Aghion and Howitt, 1992; Hall and Rosenberg, 2010), if they are (completely) free there will be no incentive to invest in new knowledge and inventions (*e.g.*, Arrow, 1962; Romer, 1990). Thus, the potential need to protect both knowledge and inventions emerges, and the discussion of the importance of IPR for this protection function gains relevance. In forming the decision whether to protect or not, a typical trade-off emerges: if we protect, only the owner of the knowledge design will use it (for some years she/he will have the monopoly power) and so the impact on economic growth will be smaller; in cases where no protection exists (which would not allow innovators to be rewarded), knowledge will be easily diffused and all adopters will benefit from associated profits without having supported the corresponding costs; in the latter case no incentive to create new knowledge will exist. Thus a greater diffusion could have a higher economic growth impact, but at the same time, the inexistence of a clear incentive could also reduce growth enhancement. This issue is only one of the several extant trade-off debates concerning the IPR-economic growth relationship.

The main purpose of this essay is to construct a survey of the theoretical and empirical literature on the relationship between IPR, technological change and economic growth as well as to expose some of the gaps in the current research. The relevance of this task is directly related to the ambiguous role that the literature has identified relating to the relationship between these dimensions. After systematization of the relevant theoretical literature, we focus on the empirical studies concerning the effect of IPR protection on innovation and economic growth. In presenting this overview, we intend to analyse to what extent empirical results allow for a consensual conclusion, faced as we are with the ambiguity of the theoretical contributions.

The present chapter is structured as follows. After a brief introduction, Section 2.2 presents an overview of the relationship between the economics of IPR, innovation and technological change. Section 2.3 focuses in detail on the relationship between endogenous economic growth and IPR from a theoretical perspective, whereas Section 2.4 offers an analysis of this relationship, but in empirical terms. Section 2.5 concludes, highlighting the main gaps that currently exist in this research agenda.

2.2. The economics of IPR and innovation: an overview

The conceptualization of IPR as a means of protecting ideas is relatively recent. Several international agreements, such as the General Agreement on Tariffs and Trade (GATT), Trade-Related aspects of Intellectual Property Rights (TRIPS) and the World Intellectual Property Organization (WIPO) are examples of conventions and/or organizations connected with IPR (Senhoras, 2007).

IPR, in their various forms, play a crucial role in innovation systems.[3] Firms invest in innovation activities, find new products or new processes and increase their profits. To prevent the imitation of their innovations, firms can benefit from IPR protection. In this sense, IPR serve as an incentive for innovation, since knowledge has the characteristics of a public good (non-excludable and non-rival), and hence is easily appropriable. So in the case of IPR, the good is non-rival but becomes excludable. The significance of spillovers associated with technological knowledge being widely recognized, the related literature clearly stresses the importance of property rights, patents and other policies designed to protect innovative firms from spillovers. Nevertheless, spillovers are crucial for technology transfer and development (*e.g.*, Hall and Rosenberg, 2010). Hence, within this framework, a topic that is frequently discussed concerns the optimal patent length and the consequent trade-off between dynamic efficiency and static efficiency.

IPR play an important role not only in the innovation system but also on structural dynamics across sectors and countries, and over time. Authors such as Langford (1997) conclude that, despite there being some disadvantages, one of the most important economic effects of IPR is that they induce innovation, increasing the possibilities of technology transfer.

Resources, competences and dynamic capabilities are addressed within this wider broader discussion concerning appropriability. According to Hall and Rosenberg (2010: 689), "resources are firm-specific assets that are difficult, or impossible, to imitate. They are stocks, not flows." Resources are most likely to be intangibles; they are not easily transferred, some examples being intellectual property rights and know how processes. As regards competences, they "are a particular kind of organizational resource", since "[t]hey result from activities that are performed repetitively or quasi-repetitively" (Hall and Rosenberg, 2010: 690). So routines are closely linked to competences. The firm's resources are considered sources of advantage, and in this

3 Arrow (1962) was a pioneer in addressing the economics of IPR. However, early authors such as Adam Smith, John Stuart Mill and J. W. Goethe had already conceived the patent as a price society must pay for discovery, which was fundamental for the unfettered diffusion of useful knowledge. Furthermore, it had already been recognized that the complete specification of the patent made the technological details more accessible to others (Mokyr, 2009).

context, IPR correspond to firm-specific, intangible resources, which are not easy to transfer to other firms because it is difficult or even impossible to imitate them.

According to Mokyr (2009) and others, it is important to pay attention to the difference between institutions which stimulate technological progress and institutions that support the growth of markets by protecting property rights. In a completely unlegislated society, technological progress is less likely. Yet in order for rapid technological change to occur, it is necessary to eliminate some property rights. So this author is forced to ask "What kind of institutions encouraged technological progress?" (Mokyr, 2009: 349). He starts by emphasising the idea that incentives are a requirement for inventions and IPR offer incentives for successful inventors. Using the historical fact that the number of patents was stagnant until the mid- 18^{th} century, and suddenly started growing in the 1750s, the author concludes that IPR show how institutions contributed to the origins of the Industrial Revolution. However, Mokyr (2009) also states that the main difficulty lies not in whether the patent system has a positive effect on technological progress in equilibrium but whether the effect could be sufficiently large to explain a considerable share of the acceleration in technological progress that it is intended to explain. Furthermore, it is interesting to know whether other institutions could have been similar to or even more important than the patent system. Mokyr (2009) concludes that, even as far as the historical importance of patents on the Industrial Revolution is concerned, the impact is not clear.

Cozzi (2009) discusses the possibility of innovation and growth without IPR. His main line of reasoning is that, since the main engine of economic growth is innovation, IPR may not necessarily be crucial for innovation and growth. In other words, although the IPR regime allows innovators to be rewarded for their innovations, constituting a mechanism whereby they are stimulated to innovate, innovation is still possible in the absence of IPR through other means, such as education (see also Greennhalgh and Rogers, 2007). Furukawa (2007) and Horii and Iwaisako (2007) also show that increasing patent protection against imitation has ambiguous effects on R&D and growth.

Hence, we may question whether the rise in profits associated with a patent increases the incentive to innovate. Initially the answer would be that two incentives are better than just one (Cozzi, 2009). However, as Cozzi (2009) also mentions, Haruyama

(2009) proves that this is not always the case, because in a very populated world, the introduction of IPR could have adverse effects on the skill premium, which could consequently lead to a reduction in the tacit knowledge incentive and intensify the expected capital loss resulting from obsolescence.

The issue of appropriability is of course related to “profiting from the innovation framework” (Hall and Rosenberg, 2010: 698) and to Schumpeter’s concept of creative destruction. According to Hall and Rosenberg (2010), to guarantee profits from innovation efforts and to protect inventors/innovators from imitators, two possibilities are presented: strong natural protection and strong intellectual property protection, both of which are related to appropriability regimes. Patents can also be a means of protecting inventors/innovators from their rivals and ensuring the generation of profits. However, the use of patents is considered imperfect because “they are especially ineffective at protecting process innovation” (Hall and Rosenberg, 2010: 700). The authors defend that this ineffectiveness is associated, *e.g.,* with the existence of considerable legal and financial requirements to prove they have been violated or with the presence of weak law enforcement relating to intellectual property Thus patents act as an incentive to innovate while at the same time possibly discouraging some innovators and therefore reducing knowledge spillovers (Panagopoulos, 2009). Therefore, a concave relationship between patent protection and innovation may emerge, differing from the relationship advocated by Arrow (1962), which argues that stronger patent protection brings about more innovations.

In brief, some authors criticize the argument that strong patent protection offers greater incentives to innovators and therefore increases economic performance. Cohen *et al*. (2000) maintain that the increasing number of patents is not necessarily a sign of their greater effectiveness. Both empirical contributions such as those of Hall and Ziedonis (2001) and theoretical approaches such as those of O’Donaghue *et al*. (1998) lend support to this latter perspective. Moreover, as also stressed by Panagopoulos (2009), Horii and Iwaisako (2005) maintain that stronger intellectual property protection reduces the number of competitive sectors. Since it is easier to innovate in these sectors than in monopolistic sectors, this study advocates that the innovator tends to be concentrated in a smaller number of competitive sectors.

Chu (2009b) studies the effects of IPR on the specific framework of macroeconomics. He stresses that since it is not possible to meet or recreate ideal situations in the real world, market failures can engender the overprovision or underprovision of certain resources. In fact, whereas the competitive market or Walrasian equilibriums are efficient, leading to the Pareto efficient allocation of resources, competitive conditions are difficult to come by in real economies. For example, investment in R&D activity has two implications in terms of returns: the social return and the private return. Empirical studies in this area (*e.g.*, Jones and Williams, 1988, 2000) show that the social return to R&D is much higher than the private return. This being the case, R&D, innovation, economic growth and social welfare would increase towards the socially optimal level were market failure to be overcome. Within this context, Chu (2009b) stresses the relevance of quantitative dynamic general-equilibrium (DGE) analyses for studying the macroeconomic repercussions of rising IPR protection. He further emphasises that, although some empirical evidence points to a positive relationship between IPR protection and innovation, this evidence appears to be stronger in the case of developed rather than developing countries. Hence, this author maintains that the optimal level of patent protection[4] leads to a trade-off between the social benefits of improved innovation and the social costs of multiple distortions and income inequality. In an open economy, achieving the globally optimal level of protection demands international coordination rather than the harmonization of IPR protection.

Another interesting question in terms of policy implications is the magnitude of welfare gains from changing the patent length towards its socially optimal level. Kwan and Lai (2003) found that the extension of a patent's effective lifetime would lead to a significant increase in R&D and welfare. But Chu (2009a) maintains that while the extension of patent length beyond 20 years leads to a negligible increase in R&D and consumption, the limitation of the patent length leads to their significant reduction. So it seems that patent length is not an effective instrument for increasing R&D in most

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[4] Relative to patent policy, there are some instruments that can be used to influence the incentives to R&D and innovation, to the extent that they will affect economic growth. One example of these instruments is the patent length that establishes the statutory term of patent. Judd (1985) cited in Chu (2009b) argues that the optimal patent length is infinite, whereas Futagami and Iwaisako (2003, 2007) maintain, in a version of the Romer model, that the optimal patent length is finite.

industries. In line with this argument, patent reform in the USA implemented in the 1980s focused on other aspects of patent rights such as patentability requirements (the invention would have to be new and non-obvious). Nevertheless, O'Donoghue and Zweimuller (2004) also show that if the patentability requirements are lowered, there will be contrasting effects on R&D and innovation. On the one hand, it becomes easier for an inventor to obtain a patent, which increases the R&D incentives. On the other hand, the amount of profits generated by an invention would decrease due to its smaller quality improvement, so the possibility that the next invention is patentable takes away market share from the current invention, decreasing R&D incentives. The policy implication mentioned by Chu (2009b) is the ambiguous effect of lowering the patentability requirement on R&D and growth.

Another instrument also discussed in Chu (2009b) is the patent breadth (the broadness or the scope of a patent) that determines the level of patent protection for an invention against imitation and subsequent innovations. There are two types of patent protection: the lagging breadth and the leading breadth. In relation to the former, Li (2001), using the Grossman and Helpman (1991b) model, found a positive effect of the lagging breadth on R&D and growth; *i.e.*, the increase in protection against imitation improves the incentives for R&D. This unambiguous positive effect emerges because larger lagging breadth allows monopolists to charge a higher mark-up (Li, 2001).

According to Chu (2009b), Chin (2007), Furukawa (2007) and Horii and Iwaisako (2007) also show that the increase in patent protection against imitation exerts ambiguous effects on R&D and growth. Chu (2009b), basing his hypothesis on these three works, concludes that if IPR protection has asymmetric effects on different generations of households, it can also have a negative effect on innovation. Leading breadth is also discussed, underlining the point that increasing leading has opposite effects on the incentives for R&D. Once more, Chu (2009b) reports on O'Donoghue and Zweimuller (2004) and their analysis of Grossman and Helpman's (1991b) model to show the following: while the profits generated by an invention increase due to the consolidation of market power through generations of inventors, leading to a positive effect on R&D, the delayed rewards from profit sharing occasion a lower present value of profits received by an inventor, thus bringing about a negative effect (the profit growth rate is lower than the interest rate). This negative effect is also known as blocking patents (Chu, 2009b).

To sum up, we can conclude from the analysis of the different studies discussed above that the relationship between IPR and economic performance is ambiguous.

Although the codification of patents and copyright laws, as well as the regulation of privileges, emerged in the late 15th century, the concern with the relationship between IPR and economic growth only began in the 20th century, gathering pace as time went on. The first really relevant studies regarding IPR and growth emerged around the 1980s or even 1990s,[5] which corresponds with the emergence of the New Economic Growth Theory, also known as the Endogenous Economic Growth Theory, in the 1980s (Romer, 1994). The next section discusses and compares these two issues.

2.3. The bridge between IPR and Endogenous Economic Growth: main theoretical contributions[6]

Innovation has assumed increasing importance in economic growth theory. In this context, it is consensually recognized as a crucial engine of growth (for example, Romer, 1990; Aghion and Howitt, 1992), and many studies have discussed the role of knowledge and technology in growth and development (*e.g.*, Hall and Rosenberg, 2010).

In particular, some authors focus their attention on the relationship between IPR and growth. For instance, Dinopoulos and Segerstrom (2010) develop a model of North-South trade with multinational firms and economic growth in order to formally evaluate the effects of stronger IPR protection in developing countries. These effects have been

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[5] Towse and Holzhauer (2002) have compiled a selection of the most important articles relating to the economics of intellectual property, and show that, in essence, they are of 20th century provenance, belonging in particular to the 1980s and 1990s. Additionally, on 29th September 2011, in a piece of internet research conducted in "SCOPUS", using "Intellectual Property Rights" and "endogenous growth model" as search words (in all text) and collecting only journal articles (including reviews), we obtained 56 records, the first dating from 1991.

[6] The selection of these studies was based on Towse and Holzhauer (2002), Pejovich (2001), Cantwell (2006) and on a thorough search of related literature on several international bibliographic databases, including Econlit and Scopus.

the subject of intense debate, with one side advocating stronger IPR protection reform[7] and the other opposed to this (Taylor, 1994).

The former view argues that the reform would promote innovation and benefit developing countries because it would contribute to more rapid economic growth and would accelerate the transfer of technology from developed to developing countries. The latter argues that stronger IPR protection would neither accelerate economic growth nor transfer international technology more quickly, since it only "results in the transfer of rents to multinational corporate patent holders headquartered in the world's most advanced countries especially in the US" (Dinopoulos and Segerstrom, 2010: 13).

Dinopoulos and Segerstrom (2010) also offer an overview of several contributions focusing on multinationals and relating to this issue. Glass and Saggi (2002), Sener (2006) and Glass and Wu (2007) show an unambiguous relationship between strong IPR protection in the South and a lower rate of technology transfer, while Helpman (1993), Lai (1998), Branstetter *et al.* (2006) and Branstetter *et al.* (2007) reach the opposite conclusion. However, according to Dinopoulos and Segerstrom (2010), it is worth mentioning that, in all those previous models, the absence of R&D spending by affiliates, which is not empirically sustained, is assumed. Dinopoulos and Segerstrom (2010: 14), in an effort to be coherent in considering this empirical evidence, consider that "R&D conducted by the affiliates in developing countries is focused on the absorption of patent-firm technology and on its modification for local markets." This study finds a positive relationship between stronger IPR in the South and a permanent increase in the rate of technology transfer from the North to the South. Additionally, this strong protection in the South results in a temporary increase in the Northern innovation rate and in a permanent decrease in the North-South wage gap. Hence, the same authors conclude that, under these conditions, Southern strong IPR protection promotes innovation in the global economy and this explains the faster growth of several developing countries compared with the growth performance of typical developed countries.

[7] This reform emerged from the Uruguay Round in 1994, more specifically from the TRIPS agreement, whose aim was to establish minimum standards of IPR protection by all WTO members up to 2006.

Moreover, Dinopoulos and Segerstrom (2010) analyse the long-term welfare effects, and at this level some contradictions emerge. In some North-South trade models, such as those proposed by Lai (1998), Branstetter *et al*. (2007) and Glass and Wu (2007), patent reform increases the economic growth rate permanently (and therefore the consumers must be better than they would be without patent reform). In other models, such as in Glass and Saggi (2002) and Sener (2006), patent reform permanently decreases the economic growth rate (and consequently consumers must be worse). In Dinopoulos and Segerstrom's (2010) model, growth is semi-endogenous and so the long-term welfare effects are ambiguous, because patent reform does not permanently alter the economic growth rate. Nevertheless, by combining all the effects gleaned from the related literature, the authors find optimistic long-term welfare effects in those developing countries with strong IPR protection. Moreover, as regards the two possible ways of transferring technology between two countries, FDI (Foreign Direct Investment) and imitation, Dinopoulos and Segerstrom (2010: 15) argue that "the effects of stronger IPR protection would depend on how important each mode of technology transfer is."

Regarding IPR protection in an open economy, Chu (2009b) emphasises three main results derived from Lai and Qui (2003) and Grossman and Lai (2004). The first indicates that, due to the asymmetries in terms of innovation capability, developed/Northern countries tend to choose a higher level of IPR protection than developing/Southern countries. The second underlines the fact that if the North's level of IPR protection such as TRIPS were imposed on Southern countries, it would lead to a welfare gain (loss) in the North (South). And finally, although TRIPS require the harmonization of IPR protection, this harmonization is neither necessary nor sufficient for the maximization of global welfare.

Chu and Peng (2009), quoted by Chu (2009b), also consider the effects of IPR protection on income inequality across countries and find that stronger patent rights in one country tend to lead to an increase in economic growth and income inequality both in domestic and foreign countries. Another result of this research is that TRIPS tend to improve or reduce global welfare according to the domestic importance of foreign goods. Thus only if these goods were sufficiently important for domestic consumption would the harmonization of IPR protection that the TRIPS require improves global welfare.

Cozzi (2009) also highlights the role of IPR in economic growth in both developed and developing countries. Typically, while the developed countries are the Northern countries, which create new varieties of goods and services, the developing countries are the Southern countries, which have a production cost advantage. In this sense, the source of growth is the horizontal innovation of new intermediate products. In the case of Northern firms, they may export intermediate goods, they may directly invest in the South (through knowledge transfer), or they may grant a licence for their product (complete transfer). These firms desire to transfer the maximum possible knowledge, but this implies the transfer of more knowledge about their patented goods. The Southern firms can try to undertake costly imitation activities, so that in the South IPR protection is not complete: the more intensive is the knowledge transfer, the higher is the probability of Southern firms imitating their Northern counterparts. The greater is the IPR protection, the higher is the equilibrium FDI,[8] which makes it possible to improve the international division of labour. Thus, while very high IPR protection implies licensing – this method being the most efficient – very low IPR protection induces the firms of the North not to transfer at all, but to produce domestically and to export their intermediate goods to the South. The advantage of this last situation is the absence of unproductive Southern imitation costs. Cozzi (2009) also maintains that different IPR effects can exist: the combination of the general equilibrium effects of adverse incentives and wasteful imitation costs implies that the increase in international IPR protection is beneficial to the welfare of the South if the initial level of IPR is already above a certain threshold. However, in the case of weak protection of initial IPR, the increase in protection might be dangerous for Southern consumers.

Globalization, inequality and innovation are phenomena crucially associated with IPR. Spinesi (2009) extended Dinopoulos and Segerstrom's (1999) work on Schumpeterian economic growth, by studying the relationships between all those dimensions. Among others issues, Spinesi (2009) emphasises that IPR achieve a similar

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[8] The relationship between IPR protection and FDI is also analysed by Chu (2009b): technological transfer between Northern and Southern firms occurs to a significant extent *via* FDI.

result even in the presence of constant returns to scale. This result is advantageous because it would also apply in the case of firms competing *a la* Bertrand. Moreover, he finds that, while horizontal innovation has a positive level effect, it is vertical innovation that sustains the growth effect.

Panagopoulos (2009) explores the relationship between patent breadth and growth, by studying how patent breadth affects innovation and output. This study finds an inverted U-relationship between patent protection and growth.

From the different studies mentioned above, we conclude that there is no consensus regarding the relationship between IPR and economic growth, including within the specific theoretical framework of endogenous growth literature. In Table 2.1 we offer a systematization of this theoretical literature.

Table 2.1: The impact of IPR on innovation and growth: a synthesis of the theoretical literature

IPR conceptualization	Author (date)	Net final effect
Patents	Scherer (1977); Koléda (2008)	On innovation: 0
	Tandon (1982); David and Olsen (1992)	On welfare: +
	Merges and Nelson (1994)	On technological progress: -
	Taylor (1994)	On economic growth: + (symmetric protection) and – (asymmetric protection).
	Michel and Nyssen (1998); Goh and Oliver (2002); Iwaisako and Futagami (2003)	On economic growth: +
	Futagami and Iwaisako (2007)	On economic growth: + (finite patent length) and – (infinite patent length); a patent strategy with a finite patent length is optimal.
	Naghavi (2007)	On South welfare: + (if attract foreign investment in less R&D intensive industries or if they stimulate innovation in high technology sectors).
	Dinopoulos and Kottaridi (2008)	On economic growth and on income distribution: + (if each country selects the level of patent enforcement optimally, with the North having an incentive to choose stronger IPR protection than the South).
	Eicher and Garcia-Peñalosa (2008); Chu (2009a)	On economic growth: 0
	Panagopoulos (2009)	On economic growth: a concave relationship.
Index of Patent Rights from Park (2008)	Chu (2010)	On economic growth: +; on income inequality: 0
Patent length and breadth; protection trademarks; copyrights and trade secrets; and the degree of enforcement.	Kwan and Lai (2003)	On economic growth: optimal degree of IPR protection.
Copyright	Novos and Waldman (1984)	On social welfare: +
	Landes and Posner (1989)	On welfare associated with a given work: -
Patent length and breadth; copyright policy	Furukawa (2007)	On economic growth: - (when the impact of accumulated experience on productivity is large enough, an inverted U relationship is suggested).
Increase in imitation costs	Stryszowski (2006)	On economic growth in technologically lagging countries: 0

	Glass and Saggi (2002); Mondal and Gupta (2008)	On innovation and on FDI: -
	Mondal and Gupta (2009); Connolly and Valderrama (2005)	On welfare: + (both in North and in South, although the marginal welfare gain is higher in the former than in the latter)
	Wu (2010)	On innovation: +
Tariffs; Increase in the costs of imitation	Datta and Mohtadi (2006)	On South's economic growth: tariffs (-); IPR (-)
Imitation intensity	Mondal and Gupta (2006); Glass and Wu (2007); Zhou (2009)	On innovation: 0
	Dinopoulos and Segerstrom (2010)	On innovation: +
Imitation probability and the return of innovation.	Horii and Iwaisako (2007)	On economic growth: 0
Royalties	Saint –Paul (2008)	On welfare: +
N/a	Furukawa (2010)	On innovation: inverted U

N/a: not applicable; 0: ambiguous or inconclusive net effect; +(-): positive (negative) net effect.
Own elaboration.

As mentioned above, the relevant theoretical literature points to both positive and negative effects of patent protection on innovation (Chu, 2009b). For example, Furukawa (2007) and Eicher and Garcia-Peñalosa (2008) refute the idea that stronger IPR protection is always better. Using an endogenous growth model with costless imitation, Furukawa (2007) proves that IPR protection cannot increase economic growth, whereas Eicher and Garcia-Peñalosa (2008) support the idea that the relationship between IPR and economic growth is ambiguous. Iwaisako and Futagami (2003), Mondal and Gupta (2006) and Futagami and Iwaisako (2007) identify two opposite effects on this relationship. Wu (2010) presents inconclusive results that depend on such features as the countries' level of development or the channel of technology transfer. Scherer (1977) also maintains that patents involve an impact that depends on such factors as the market position of the innovator, the features of the technology (whether it is easy or difficult for it to be imitated), the cost, the risks and the potential payoffs from innovation. Furukawa (2010) and Panagopoulos (2009) find an inverted-U relationship between IPR protection and innovation (and economic growth). Kwan and Lai (2003) and Connolly and Valderrama (2005) argue that IPR are important to R&D investment and welfare.

Table 2.1 is also helpful in showing that different authors use different concepts of IPR. Some of them (Scherer, 1977; Tandon, 1982; David and Olsen, 1992; Merges and Nelson, 1994; Taylor, 1994; Michel and Nyssen, 1998; Goh and Oliver, 2002; Iwaisako and Futagami, 2003; Futagami and Iwaisako, 2007; Naghavi, 2007; Dinopoulos and Kottaridi, 2008; Eicher and Garcia-Peñalosa, 2008; Koléda, 2008; Chu, 2009a; Panagopoulos, 2009) limit the definition of IPR to one of their forms – patents (considered as the most important form of IPR, as discussed above). Others use distinct definitions, *e.g.*, Glass and Saggi (2002) and Mondal and Gupta (2008, 2009), who define IPR as the rise in the imitation cost. Connolly and Valderrama (2005) give a similar definition, assuming that imitators pay a licence fee which is similar to an increase in the fixed cost of the imitative research; Kwan and Lai (2003) consider IPR part of the imitation rate which can be influenced by some factors such as patents, trademarks, copyrights and trade secrets; Furukawa (2007) also defines IPR as a mixed measure of patent and copyright; Glass and Wu (2007) associate the measure of IPR with imitation intensity, whereas Dinopoulos and Segerstrom (2010) define IPR as a reduction in the exogenous rate of imitation.

Despite these different ways of defining IPR, we do not find evidence of significant differences in terms of the results obtained. In fact, we have two studies in the table that achieve the same results using different measures of IPR: Furukawa (2007) and Panagopoulos (2009). Both suggest an inverted U relationship between IPR and economic growth, although the former defines IPR as a mix of patent and copyright measures, while the latter defines IPR only as patents. Furukawa (2010) also finds the same relationship although he does not define IPR.

Two of the articles in Table 2.1, Stryszowski (2006) and Mondal and Gupta (2008), compare their assumptions and/or conclusions with other studies – some of them also analysed in the present work. Stryszowski (2006) identifies and discusses studies which maintain that strong IPR protection is beneficial for innovating economies (*e.g.*, Connolly and Valderrama, 2005). However, this study also highlights works that have found negative effects of IPR protection on lagging economies, based on the existence of a mechanism in which strong IPR protection tends to raise consumer prices and to diminish trade benefits that could be essential for developing economies (for example, Helpman, 1993). Mondal and Gupta (2008) discuss several studies based on their distinct assumptions concerning the innovation framework (quality ladder framework *versus* product variety framework), and the alternative ways of treating imitation and of strengthening IPR protection, *etc*. Following this they present the assumptions of their own model, characterized by the use of a product variety model, a North-South model with endogenous innovation, imitation and multinationalisation, where innovation activities are set as costly and there is an endogenous rate of imitation. Lai (1998) gives a close approximation to the latter, except for two features: the endogenous imitation rate in the South, given that imitation is considered costly; and the introduction of two kinds of labour in the South – skilled and unskilled. In line with these two distinct assumptions, the results achieved are also different from Mondal and Gupta's (2008).

To sum up, we can state that the studies presented in Table 2.1 do not show a pattern regarding the relationship between IPR and economic growth (*via* welfare, for instance). From this table we can also state that patents are the most widely used measure of IPR in theoretical works. Hence, at this stage, we state the existence of two main gaps in this literature: the scarcity of studies, so that a potential research line would be to dig more deeply in this field; and the excessive focus on patents as an IPR measure, which neglects the potential impact of other instruments, such as copyrights, which are crucial for the development of specific ICT industries such as information technology and software.

In the next section we develop an analysis of the empirical studies concerning this same relationship between IPR and endogenous economic growth.

2.4. IPR and Endogenous Economic Growth: where do we stand? Insights from the empirical literature

After the systematization of the relevant theoretical literature in the previous section, we focus on empirical studies into the effect of IPR protection on innovation and on economic growth. In this review (*cf.* Table 2.2), we intend to show whether the empirical results permit us to reach a sustainable conclusion, faced as we are with the confirmed ambiguity of the theoretical contributions.

Table 2.2: The impact of IPR on innovation and growth: a synthesis of the empirical literature

Measure of IPR	Methodology	Sample	Author (date)	Net estimated effect
Park and Ginarte (1997) Index of Patent Rights[9]	Econometric analysis – Seemingly Unrelated Regressions (SUR)	Cross-section of countries for the period 1960-1990.	Park and Ginarte (1997)	+
	Econometric analysis – cross section	48 countries for the period 1980 and 2000 (Sources: World Intellectual Property Organization (WIPO) and Penn World Table 6.1)	Xu and Chiang (2005)	
	Econometric analysis – panel data	64 developing countries over the 1975–2000 period (Sources: World Development Indicators and Statistical Yearbook by UNESCO (UNESCO, 1995, 1997, 2000); patent data come from the United States Patent and Trademark Office Website)	Chen and Puttitanun (2005)	
		79 countries and four sub-periods: 1975-79, 1980-84, 1985-89 and 1990-94.	Falvey *et al*. (2006)	+ (for low-income and high-income countries)
		80 countries for the period 1970–1995. (Sources: PennWorld TableMark 6.1, updated version of Summers and Heston, 1991; UNCTAD, 2005; World Bank, 2005; Ginarte and Park, 1995; Easterly and Sewadeh, 2005; Hall and Jones, 1999; and Barro and Lee, 2000).	Groizard (2009)	**Ambiguous:** + (FDI is higher for countries with stronger intellectual property protection). - (Negative relationship between IPR and human capital indicators).

[9] This index is a simple sum of the scores attributed to each of the five categories of patent rights (score from 0 to 1) on a scale of 0 to 5, with a larger number indicating stronger patent rights. The five IPR categories are the patent duration, the coverage, the enforcement mechanisms, the restrictions on patent scope and the membership in international treaties.

		69 developed and developing countries over the period 1970–1999 (Sources: World Bank's World Development Indicators, 2001; Jon Haveman website; OECD's International Trade by Commodity Statistic (Historical Series, 1961–1990); International Trade by Commodity Statistic, 1990–1999; and Barro and Lee, 2001, database).	Falvey *et al.* (2009)	**Nonlinear:** (Depends on level of development, the imitative ability and the market size of the importing country).
Ginarte and Park (1997) Index of Patent Rights[10]	Econometric analysis	50 countries (Sources: Ginarte and Park, 1997; Sachs and Warner, 1995; Hofstede, 1984 and UNESCO, 1998).	Varsakelis (2001)	+
		32 countries for the period between 1981 and 1990 (Sources: Ginarte and Park, 1997; Esty *et al.*, 1998; United Nations, 1999; Word Bank, 2000; Barro and Lee, 2000; Heston *et al.*, 2001 and Pick's Currency Yearbook and World Currency Yearbook, several years).	Kanwar and Evenson (2003)	
Eight indexes:[11] index of patent rights constructed from Ginarte and Park (1997) and Park and Wagh (2002); index of copyrights; index of trade-marks; index of parallel import protection; index of software rights; index of piracy rates; index of enforcement provisions and index of enforcement in practice.		41 countries (Sources: Penn World Tables (Version 5.6a), World Bank Development Indicators and UNESCO's Statistical Yearbook).	Park (2005)	
Patent rights index data (Park, 2001)	Semiparametric model	21 countries for the period 1981 and 1997 (Sources: World Bank World Development Indicators, 1999; and UNESCO).	Alvi *et al.* (2007)	
Patents	Econometric analysis	Firms in the chemical, drug, electronics and machinery industries	Mansfield *et al* (1981)	
		Japanese and U. S. patent data on 307 Japanese firms (Sources: Japan Development Bank Corporate Finance Database, Kaisha Shiki Ho R&D, JAPIO, CASSIS CD-ROM, RAI patent database and Hoshi and Kashyap, 1990).	Sakakibara and Branstetter (2001)	**0**
		4 countries (manufacturing sector divided into 12 subgroups) between 1990 and 2001 (Sources: OECD STAN, EPO and PERINORM).	Blind and Jungmittag (2008)	+

[10] This index was constructed for 110 countries in the period between 1960 and 1990. Moreover, it is constituted by five categories: extent of coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms and duration of protection. Similarly to Park and Ginarte (1997), this index extends from zero to five and its overall value is obtained by the weighted sum of the values of the five categories.

[11] For the first three indexes (relative to patents, copyrights and trade-marks) the index consists of four sub-categories: coverage, duration, restrictions and membership in international treaties. Enforcement can also be included as a sub-category (such as in Ginarte and Park, 1997) but it was considered useful to separate this sub-category and treat it as another index.

Impact of patent reform[12]		16 countries over the 1982-1999 period (Sources: U.S. Bureau of Economic Analysis (BEA) Survey; World Intellectual Property Rights Organization (WIPO)).	Branstetter *et al.* (2006)	
N/a (property rights)		68 developed and developing countries between 1976 and 1985 (Sources: World Development Report 1988, Summers and Heston, 1988; World Bank, 1990; and Scully and Slottje, 1991).	Torstensson (1994)	

N/a: not applicable; 0: ambiguous or inconclusive net effect; + (-): positive (negative) net effect.
Own elaboration.

[12] "Each reform can be classified according to whether or not it expanded or strengthened patent rights along five dimensions: 1) an expansion in the range of goods eligible for patent protection, 2) an expansion in the effective scope of patent protection, 3) an increase in the length of patent protection, 4) an improvement in the enforcement of patent rights, and 5) an improvement in the administration of the patent system." (Branstetter *et al*., 2006: 14).

As we have seen above, according to the theoretical literature, patent protection generally has positive and negative effects on innovation (*e.g.*, Chu, 2009b). However, empirical studies usually find a positive effect, which according to Chu (2009b) is explained by the domination of the positive effects over the negative ones. As we can see in Table 2.2, the empirical evidence suggests a positive relationship between IPR protection and innovation although with some ‘restrictions’ in the sample. For instance, the positive result is true only for developing countries (Falvey *et al.*, 2009; Chen and Puttitanun, 2005). At a first glance, we could expect the opposite result. However, while some works, for example Park (2005) and Kanwar and Evenson (2003), generally find a positive effect, Chen and Puttitanun (2005) explain that, on the one hand, lower IPR can facilitate imitation, while on the other hand, innovation in developing countries increases in proportion to greater IPR protection. Moreover, these authors state that the optimal degree of IPR protection may depend on the country’s development level. Furthermore, Falvey *et al*. (2006) find evidence of a positive effect between IPR and economic growth for both low and high-income countries, but not for middle-income countries. According to the latter, the positive relationship between IPR and economic growth in low-income countries cannot be explained by the potential fostering of R&D and innovation, but by the idea that stronger IPR protection promotes imports and inner FDI from high-income countries without negatively affecting the national industry based on imitation.

Hence, when the division between developed and developing countries is considered, the effects of patent rights on R&D are rendered ambiguous: for instance, according to Chen and Puttitanun (2005), in developing countries there is a positive and significant relationship between IPR protection and innovation, while according to Park (2005), there is an insignificant effect of IPR protection on R&D. Chu (2009b), in giving a plausible explanation for this contrast emanating from empirical analyses, points to the fact that developed countries are typically close to the technology frontier, and that consequently economic growth in these countries requires original innovations, while developing countries are normally further away from the technology frontier, thus enabling economic growth to be driven by the reverse engineering of foreign technologies. Therefore, stronger patent rights, which discourage the reverse engineering of foreign technologies, can asphyxiate the innovation process in developing countries. Chu (2009b) emphasises that the increase in the level of patent protection by policymakers is similar to giving more market power to monopolists, which intensifies the deadweight loss. The author recalls Nordhaus' (1969) contribution in stating that the optimal level of patent protection should trade-off the harmful effects of IPR protection on society, even when stronger patent rights are growth-enhancing, against the welfare gain from innovation. Hence, distortionary effects of IPR protection could emerge. The latter author also emphasises that, when skilled and unskilled workers are assumed, strong patent protection increases the return to R&D and the wage of R&D workers.

Through analysing the net effect of the IPR on economic growth we can state that it is not easy unequivocally to draw conclusions regarding the sign of that effect, despite the prevalence of the positive sign (*cf*. Table 2.2). We find evidence of both a positive sign and a negative sign. Possible explanations, beyond the focus on a patent index for measuring IPR (as also highlighted by Chu, 2009b, which mentions that it is not clear how each type of patent rights influences innovation on empirical grounds), are: the fact that some studies do not analyse the direct effect between IPR and economic growth; the adoption of different methodologies and of distinct samples. Hence, the gaps already mentioned when discussing the theoretical contributions clearly emerge here in association with the empirical studies. Once again, insufficient analysis, even more striking at the empirical level, and the excessive focus on patents as means of IPR measurement are evident.

2.5. Concluding remarks

This study supports the conclusion that there is no clear relationship between IPR and economic growth. Theoretical literature indicates that IPR protection has positive, negative or even ambiguous (or inconclusive) effects on innovation.

After a thorough review of this theoretical literature it has been possible to identify some gaps in the research agenda. Firstly, in general, this research does not study the direct and net effect of IPR on economic growth. In fact it only analyses the relationship between IPR-induced factors and economic growth, or the impact of IPR on other economic indicators such as welfare, technological change, FDI, R&D, innovation, *etc*. This happens because a standard argumentation is adopted, maintaining a strict relationship between these elements and economic growth. For instance, Mondal and Gupta (2006: 27) point out that "[t]echnological change plays the most important role in determining a country's rate of economic growth. Strengthening the Intellectual Property Rights (IPR) is an important factor that motivates technological change". Furthermore, Koléda (2002: 1) argues that "[i]nnovation is an important source of economic growth". Mansfield (1986: 173) holds that "[t]he patent system is at the heart of our nation's policies toward technological innovation." Secondly, there is a disproportionate focus on patent measurement as a proxy for IPR, and thirdly, it is clear that there is a scarcity of studies in this field, particularly in empirical terms.

Despite the divergence of results regarding theoretical studies, most empirical studies find a net positive effect, which means that positive effects of IPR protection outweigh the negative effects. A possible explanation for this is that the empirical measure of patent protection, which is typically used, is just a summary of the statistics relating to the different categories of patent rights and so it is not clear how each type of patent rights influences innovation on empirical grounds (Chu, 2009b).

From the above, we consider that more research on this specific topic is crucial in order to further advance our understanding of the relationship between IPR and economic growth on a worldwide scale, and to be able clearly to go beyond the strict modelling frame.

Chapter 3

Endogenous growth and intellectual property rights: a North-South modelling proposal

A modified version of this chapter was accepted for publication in *Economic Modelling* with the title 'Endogenous growth and intellectual property rights: a North-South modelling proposal', DOI information: 10.1016/j.econmod.2013.12.021.

3.1. Overview

There is a broad consensus in the literature regarding the understanding of innovation as vital for economic growth (*e.g.*, Aghion and Howitt, 1992; Barro and Sala-i-Martin, 2004; Acemoglu and Akcigit, 2012). Moreover, Intellectual Property Rights (hereafter referred to as IPR) are recognized as relevant for understanding innovation and thus emerge as a crucial determinant for economic growth analysis (*e.g.*, Gould and Gruben, 1996; Glass and Saggi, 2002; Sener, 2006; Dinopoulos and Segerstrom, 2010).

According to Falvey *et al*. (2009) and Chu *et al*. (2012), we would expect a positive impact of stronger IPR on economic growth. Indeed, increasing patent protection raises the R&D incentives and improves technological progress, which in turn decreases economic growth volatility, proving that a superior patent breadth leads to a higher expected growth rate. Additionally, it is common among empirical studies to find a net positive effect between IPR protection (measured by a system of patents, for instance) and innovation. In fact, the empirical evidence suggests a positive relationship between this kind of protection and innovation, despite certain characteristics of the sample, such as the type of countries in the study (for instance, the above result is significant mostly for low and high income countries but not for middle income countries), may bring some bias into the analyses (for a detailed analysis of such differences see Azevedo *et al*., 2012).

Within the literature on economic growth, important contributions to the field of IPR have been made in juxtaposition with international trade. Several questions have emerged, such as: what is the optimal enforcement of IPR in a North (South) open economy? What are the effects of introducing IPR into a North-South endogenous growth model? These questions are in line with our research aims for this chapter, as will be made clear below.

Several papers have used a North-South endogenous growth setup to deal with the above mentioned questions, specifically in terms of what is the optimal enforcement of IPR protection. Sá *et al.* (2009), for example, discuss this topic in relation to a small and developing open economy, analysing whether there should be no enforcement on the one hand or complete enforcement on the other. Their results point to the dominance of a positive relationship between IPR enforcement and welfare, albeit showing that, when departing from weak protection choices, some exceptions may be found. Wu (2010) observes that there is no consensus in the literature on the relationship between IPR protection and economic growth, since this relationship relies on the development level of the country, which imposes different necessities of innovation and imitation that affect the impact of IPR protection. Mondal and Gupta (2009) also propose an endogenous growth model that analyses the effects of IPR protection on economic growth, concluding that a strategy of strengthening IPR in the South may lead to welfare gains in both the North and the South (although the marginal welfare gain is higher in the former than in the latter), which leads to a rise in the Northern innovation rate and a decrease in both the Southern rate of imitation and the South-North wage in the new steady state equilibrium. Thus, this strategy has a positive effect on the steady state equilibrium growth rate in both countries.

In this chapter, we aim to understand the effect of introducing IPR protection into a North-South endogenous growth model and it is important to stress that our goal is to study this effect only within endogenous growth models. Therefore, we don’t take in consideration the other kind of models. Despite the important contributions that have been emerging to this research framework, the analysis is still in its infancy. In order to assess this latest evidence, we conducted a simple bibliometric exercise to gain a more quantitative picture of the research patterns concerned with IPR in the specific framework of Endogenous Growth Models (EGM). This exercise is based on two datasets gathered from the bibliographical database SciVerse Scopus.[13] Our first dataset was obtained using the terms "Endogenous Growth Model" (EGM) as search words (in all fields and choosing article and review as document type), whereas the second dataset was gathered from a similar search using the terms "Intellectual Property Rights" and "Endogenous Growth Model" simultaneously (EGM+IPR). The first set encompasses 2004 articles, while the second only comprises 71 articles.[14]

Figure 3.1 represents the temporal evolution of the number of published articles broadly about EGM and specifically about EGM+IPR. Articles on EGM (alone) have been appearing since 1991, whereas the first year in which we find published articles concerning both IPR and EGM is 1998. This comprehensive search, whose first recorded entry is in 1998, sustains the argument that the analysis of IPR in the context of endogenous growth models is a rather new research field. Furthermore, despite the visible and sustained increase in EGM related research from 1995, the number of publications relating to EGM+IPR has remained almost stable over the years in focus.

As Figure 3.1 shows, the relative weight of EGM+IPR in total EGM is small, with a peak occurring in 2012. However, there is no clear evidence of growth in relation to

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[13] Scopus is the largest abstract and citation database of peer-reviewed literature and quality web sources, having been designed and developed for over 500 users and librarians internationally. This dataset includes the abstracts and references of 15,000 peer-reviewed journals from more than 4,000 international publishers (http://www.elsevier.com/wps/find/bibliographicdatabasedescription.cws_home/705152/description#description, accessed on 22th October 2012).

[14] This search procedure is unrestricted and comprehensive in the sense that the engine searches in the whole text. Even so, it is important, bearing in mind that any bibliometric exercise bares a limitation concerning the impossibility of the chosen keyword being able to embrace the whole research in analysis (in our case, IPR and endogenous growth models related research).

this weight in the analysed time period. Faced with the fact that this line of research has only recently been undertaken, we argue that there are still important caveats that have to be dealt with, and in this chapter we intend to contribute to limiting their scope, our original aim and main motivation being to explain the IPR enforcement effects on growth, in the presence of North-South technological knowledge diffusion.

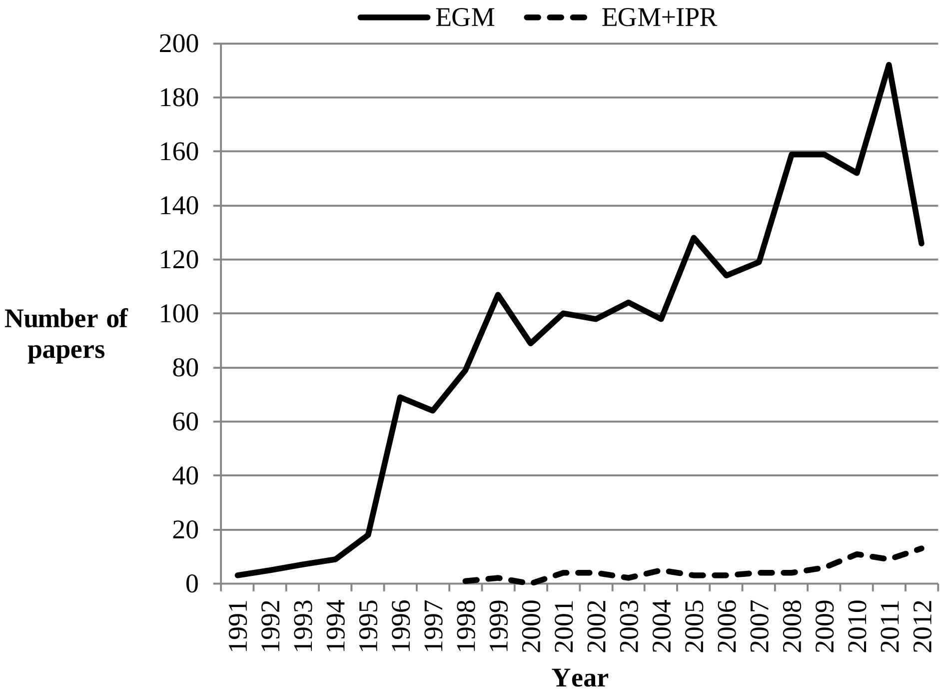

Figure 3.1. Number of published papers by year

As starting points for our modelling proposal, we consider Connolly and Valderrama's (2005) and Afonso's (2012) studies, both using a similar endogenous growth framework, which propose analogous building blocks in their models and achieve interesting results.

Nevertheless, these two articles report distinct results. Connolly and Valderrama (2005) focus on welfare and growth within a dynamic argument, arguing in favour of free trade, particularly from the point of view of developing countries. Afonso (2012) also focuses on technological knowledge diffusion issues, but in relation to the dynamics of wage inequality.

Thus our framework is based on Connolly and Valderrama (2005) and Afonso (2012), but we also draw on some studies specifically oriented towards IPR within EGM, such as those of Mondal and Gupta (2009), Sá *et al.* (2009) and Wu (2010). As in the first two studies, we also consider a model consisting of two economies (North and South) and three productive sectors in each economy: final goods, intermediate goods and designs (R&D sector). However, in comparison with Afonso (2012), we drop the hypothesis of distinct types of labour, and we do not consider transportation costs separately as in Connolly and Valderrama (2005). Moreover, we introduce a new parameter into the probability of imitation, in order to capture the effect of IPR protection, since it is an adequate procedure for showing that IPR enforcement aims at constraining imitation. Our main motivation is to contribute to overcoming the present gap in the literature on endogenous growth, given that most of the related literature, as it has been shown above with the bibliometric account, has treated IPR protection as a secondary issue or it has dealt with the relationship between IPR protection and other things, essentially between IPR protection and innovation (*e.g.*, Helpman, 1993; Lai, 1998; Yang and Maskus, 2001; Akiyama and Furukawa, 2009).

Connolly and Valderrama (2005) make reference to IPR, but commence their analysis by assuming the absence of both domestic and international IPR enforcement. Afterwards, they introduce IPR, which force Southern imitators to pay a license fee to Northern innovators, and model them simultaneously as an increase in the imitative research fixed cost and a reduction in the fixed cost of innovative research. The authors show that the presence of IPR can positively affect both Northern and Southern welfare and argue that, in a world where growth is driven by technology and Southern research affects that developed in the North, Southern nations can benefit from some degree of IPR to foreign firms. Additionally, they state that the imposition of a low level of IPR leads to superior steady state growth rates compared with Southern trade liberalization alone. Moreover, they show that the gain associated with the increase in IPR is greater for both countries, as long as the South remains open to imports of Northern intermediate goods.

Afonso (2012) does not ignore IPR, but does not explicitly model them either. For instance, the author argues that the investment in a blueprint can only be claimed if profits are positive within a given period in the future and if this is guaranteed by both costly R&D and internal patents enforcement, that is, a national IPR system which protects the leader firm's monopoly of that quality good internally though not worldwide, while simultaneously spreading learned knowledge to other national firms in line with Connolly and Valderrama, 2005).

Connolly and Valderrama (2005) and Afonso (2012) introduce IPR enforcement, but deal with this issue in a simplified manner because their main purpose was not to discuss IPR. Hence, departing from modelling frames similar to these studies, we intend to focus our research on IPR. As mentioned above, we introduce a new parameter into the probability of imitation, which is treated by following the consensual position in the literature, that IPR protection makes imitation more difficult (*e.g.*, Park and Lippoldt, 2005; Nair-Reichert and Duncan, 2008; Trommetter, 2010; Ivus, 2011). Nevertheless, it is important to stress that there is no agreement regarding the best way to introduce IPR into this type of model (see, for example, Mondal and Gupta, 2009; Sá *et al.*, 2009; Wu 2010).

Lastly, our results are related to the IPR literature (see Chu, 2009b). This literature considers that the IPR effect on economic growth is unclear. That is to say, while some studies identify a positive relationship, others identify negative or inconclusive results. However, our results are in line with Helpman (1993), Taylor (1994), Datta and Mohtadi (2006), Furukawa (2007) and Eicher and Garcia-Peñalosa (2008), who refute the idea that stronger IPR are always better.

Our work is not original neither in terms of model and mathematical formalization nor in terms of results, if we refer to each one of them separately. This work is not the only one examining the IPR in the context of product cycle model. For instance, Lai (1998), Yang and Maskus (2001) and Akiyama and Furukawa (2009) also use a North-South product cycle model but they employ a different mathematical formalization and they study, in particular, the effects of IPR on innovation while we use a mathematical formalization similar to Connolly and Valderrama (2005) and Afonso (2012) to observe the effect of IPR protection in economic growth. In addition, this is not the only study which finds a given sign for the relationship between IPR and economic growth. According to the previous statements, there are works which find either a positive, a negative or an inconclusive relationship between IPR and economic growth, as we also conclude in Azevedo *et al*. (2012). In the quoted work, we verify that the great part of the papers about IPR does not study directly this relationship or this result is not their main goal. Then, our motivation is to study the mentioned relationship using a mathematical formalization similar to Connolly and Valderrama (2005) and Afonso (2012) to find a relationship between IPR and economic growth, though. Therefore, this work distances itself from the others because we use a different framework, a different mathematical formalization, which is not original but was not applied before with this aim. In this sense, our contribution to the literature, our novelty, is to develop an EGM with IPR protection and to try to check the sign of this relationship using a different approach from the ones which have had this purpose.

The present chapter is structured as follows. After a brief introduction, Section 3.2 presents the setup of the model. Section 3.3 focuses in detail on the equilibrium and Section 3.4 concludes.

3.2. Setup of the model[15]

We assume two economies with three sectors: intermediate goods, final goods and designs (R&D sector). The former sector operates in a monopolistic competition scenario, whereas the latter two operate under perfect competition. In particular, the R&D sector is closely associated with the intermediate goods sector: when successful, R&D activities result in innovations in the North and imitations in the South, and as in Romer (1990), provide inputs to the intermediate goods sector. In turn, quality adjusted intermediate goods and labour are inputs into the final goods sector. Thus, we use a standard quality ladder model, which, by considering two countries, also follows the contributions of authors such as Grossman and Helpman (1991b), and Barro and Sala-i-Martin (1997). The final good is consumed and the fraction that is not consumed is used in R&D activities or in the production of intermediate goods.

3.2.1. Final goods sector

In the production of the competitive final good, we have established some particular premises: (i) there is a fixed number of intermediate sectors, *J*; (ii) only the top quality

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[15] The model will be solved in a more detailed way in the Appendix A.1.

good will be sold under limit pricing; (iii) the quality of each good rises with successful innovations; (iv) each quality upgrade can be considered as a step further up the ladder and the dimension of each step shows the dimension of quality upgrades. Technological knowledge is thus incorporated into intermediate goods and economic growth in each country is determined by technological developments in the quality of available inputs, independently of the country of origin. Final good can be produced both in North (country *i*=*N*) and in South (country *i*=*S*), by perfectly competitive firms, and the constant returns to scale production function at time *t* is:

$$Y_i(t) = A_i L_i^{\alpha} \sum_{j=1}^{J} (z_i(j,t))^{1-\alpha},\ i \in \{N,S\}, \tag{3.1}$$

where:

$$z_i(j,t) = q^{k_N(j,t)} x_i(j,t). \tag{3.2}$$

The exogenous productivity level is given by a positive variable A_i, which depends on the country's institutions, related, for example, to government services, property rights and tax law; we assume $A_S < A_N$. The labour input used in the production of the final good is represented by L_i, $\alpha \in [0,1]$ being the labour share. $z_i(j,t)$ is the quality adjusted intermediate good *j* at time *t*. *q*, an exogenously fixed constant larger than 1, expressing the size of each quality improvement achieved by each success in R&D. The steps of the quality ladder are represented by *k*, with greater *k* indicating greater quality. The quality adjusted rank of *j* will increase from 1 (q^0=1) to q^1 with the first innovation, to q^2 with the second and to q^{k_j} with the k_jth innovation, which is used due to the profit maximizing limit pricing by the monopolist producers. The quantity $x_i(j,t)$ of *j* is used along with labour to create $Y_i(t)$. $(1-\alpha)$ is the aggregate intermediate goods input share.

In whichever country, for a given $p_i(t)$ and $p(j,t)$, the implicit demand for each *j* by the representative producer of *i*th final good is:

$$x_i(j,t) = L_i \left[A_i(1-\alpha)\frac{p_i(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left[\frac{1-\alpha}{\alpha}\right]}, \tag{3.3}$$

where $p_i(t)$ is the price of the final good *i* and $p(j,t)$ is the price of intermediate good *j*.

Replacing $x_i(j,t)$ in equation (3.2) with equation (3.3), using the resulting expression in equation (3.1), and substituting $p_i(t)$ by the MC_i and $p(j,t)$ by the limit prices presented in the next subsection, the supply of final good in each country is:

$$Y_N(t) = A_N^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_N Q_N \left[n_{NN} + n_{NS}\left(1+\tau_{x_S}\right)^{\frac{\alpha-1}{\alpha}} MC_S^{\frac{\alpha-1}{\alpha}} + n_S q^{\frac{1-\alpha}{\alpha}}\right], \tag{3.4}$$

$$Y_S(t) = A_S^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_S Q_N \left[n_{NN}\left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}} + n_{NS} + n_S q^{\frac{1-\alpha}{\alpha}}\left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}}\right], \tag{3.5}$$

$$Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}. \tag{3.6}$$

Q_N is the Northern aggregate quality index; thus, aggregate production in both countries depends on Q_N, since limit pricing with free trade guarantees that only the highest quality technology will be used. Consequently, even when an intermediate good is produced in the South, its quality level is the same as the prime Northern quality level.

In a scenario of perfect competition, the marginal cost, MC, matches the price of the final good, *p*; *i.e.*, $MC_i = p_i$. In this sense, the marginal cost of producing an intermediate good is not dependent on its degree of quality and is similar across all domestic sectors. We normalize to one the Northern marginal cost, $MC_N = 1$, and we assume that the arguments yield equilibrium marginal costs that are larger in the North than in the South, $MC_N > MC_S$.

3.2.2. Intermediate goods sector

What will the country producing the intermediate goods used in the production of final goods be? The answer depends not only on trade barriers, but also on each country's degree of technological sophistication. As the North is technologically more advanced, it is the innovator in pushing the world's technology frontier further. However, we consider that the South may improve its domestic technological knowledge by imitating Northern technology, at least until the gap is eliminated.

When the knowledge of how to produce an intermediate good is internally available, this intermediate good can be produced using the final goods production function.The marginal cost of producing an intermediate good is the same as the marginal cost of producing the final good, MC_i. We assume that $0 < MC_S < MC_N = 1$, which allows the South to produce the same quality level, k, at a price lower than its Northern competitor. This makes it possible for a successfully imitating Southern firm to capture the international market.

Additionally, we consider that within a country the knowledge of how to make a good is free.[16] Distinguishing between domestic IPR and international IPR, we suppose that the former are protected. That is, the innovator is domestically protected by a system of domestic IPR, and in a set of Schumpeterian creative destruction, continues as the best quality producer. However, our focus is on international IPR, which appear to

[16] There are countries that simultaneously have enforced patents which protect the lead firm's national monopoly of a specific quality good and the associated knowledge. Hence, the other national firms cannot use this knowledge without any cost to themselves.

protect the innovator Northern country from foreign copies. Hence, from now on, we mention IPR protection to refer to international IPR protection.[17]

Following the contributions of Barro and Sala-i-Martin (2004, Ch. 7) and Afonso (2012), according to the demand in equation (3.3), the monopolist intermediate goods firms maximize their profits throughout the optimal price, given by the following mark-up:

$$p(k,j,t) = p(j,t) = p = \frac{1}{1-\alpha}, \tag{3.7}$$

which is constant over time, across firms and for all quality degrees. The nearer α is to zero, the lower is the mark-up and thus the less room there is for monopoly pricing.

The kind of competition handled by the firm influences the expected profits. There are three types of firms: Northern firms facing Northern competition, n_{NN}; Northern firms facing Southern competition, n_{NS}; Southern imitating firms facing Northern competition, n_S. Thus, there are *J* sectors, $J = n_S + n_{NS} + n_{NN}$,[18] and bearing in mind I_N and I_S (the probability of successful innovation and imitation, respectively, which will be presented in Subsection 3.2.3), we assume, such as in Connolly and Valderrama (2005), that entry and exit into n_{NN}, n_{NS} and n_S is given by:

$$\dot{n}_{NN} = I_N(1-I_S)n_{NS} - [I_N I_S + (1-I_N)I_S]n_{NN} \tag{3.8a}$$

$$\dot{n}_{NS} = I_N(I_S n_{NN} + n_S) - [(1-I_N)I_S + I_N(1-I_S)]n_{NS} \tag{3.8b}$$

$$\dot{n}_S = (1-I_N)I_S n_{NN}^f + n_{NS}^f - I_N n_S \tag{3.8c}$$

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[17] Relatively to the articles that we quote in terms of IPR discussion, it is important to highlight that the great part of them make the analysis especially in terms of international protection. However, we also consider some articles which discuss IPR internally because we consider that some of their conclusions and analysis are important to our study and to understand some issues about the IPR protection.

[18] We fix J = 1, so that *n's* will be the share of the Southern market kept by each group (Connolly and Valderrama, 2005).

Thus, Northern firms challenging Northern rivalry select a limit price slightly below q times the lowest price at which the preceding innovator could sell, as the good is q times more productive than the precursor. $MC_N=1$ is the lowest price at which the preceding innovator could sell in the North and $(1+\tau_{x_S})$ is the lowest price at which the good could be sold in the South, as it is subject to Southern tariffs on intermediates and *ad-valorem* transportation costs, τ_{x_S}. Thus Northern firms facing Northern competition, n_{NN}, have two limit prices: $P_{NN} = qMC_N = q$ for national sales and $P^f_{NN} = q(1+\tau_{x_S})$ for sales to the South.[19] At these limit prices, world sales of all obsolete technologies will be wiped out. Similarly, Northern firms challenging Southern competition, n_{NS}, have limit prices $P_{NS} = qMC_S(1+\tau_{x_S})$ internally and $P^f_{NS} = qMC_S$ in a foreign country. Southern firms, n_S, always face Northern competition and impose limit prices $P^f_S = 1$ for sales abroad and $P_S = 1+\tau_{x_S}$ for home sales. In each intermediate good, the firm with the highest quality employs pricing to remove sales of lower quality. If $q(1-\alpha)$ is greater than $MC_N = 1$, the leader will use the monopoly pricing. However, if $q(1-\alpha)$ is less than $MC_N = 1$, the leader of each industry will use the limit pricing to capture the total market. In Connolly and Valderrama (2005), the leader in each industry uses limit pricing to remove sales of lower quality.[20] Innovations are drastic, so the dimension of quality upgrades is large enough for a firm in the North to control the international market with a unique quality level upgrade over a Southern

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[19] "This holds if $q(1-\alpha) \leq 1$. If instead, $q(1-\alpha) > 1$, then Northern firms will use monopoly pricing" (Connolly and Valderrama, 2005: 13).

[20] Even without internal IPR protection, the presence of any determined cost to mimic will successfully exclude domestic copy of a national product.

imitation, $\left(q > \frac{(1+\tau_{x_S})}{MC_S}\right)$.[21] A firm in the South can win the worldwide market by imitating the leader in the North (and fixing a smaller price). Hence, there is a Vernon-type product cycle (*e.g.*, Vernon, 1966) whereby production moves from the North to the South with successful imitation, and back to the North with new innovation.

3.2.3. R&D sector

Economic growth is boosted by R&D activities. Firms decide the amount of resources to apply, based on the expected present value of profits from successful research, which depends on the probabilities of innovation and imitation. In the North, R&D activities lead to the emergence of innovative blueprints for manufacturing intermediate goods, which improve their quality. In an intermediate goods sector *j*, currently at quality level $k_N(j,t)$, $I_N(j,t)$ represents the probability at time *t* that the $(k_N(j,t)+1)^{\text{th}}$ innovation will occur and will follow a Poisson process. Similarly, we also consider that these designs are internally protected through IPR and that the leader firm in each *j* (that is, the one holding the latest patent) uses limit pricing to guarantee monopoly. The probabilities of successful innovation and imitation are essential to R&D, as the profit yields accruing during each period *t* to the monopolist and the duration of the monopoly power contribute to the value of the top patent. These probabilities creatively extinguish either the extant top design (*e.g.*, Aghion and Howitt, 1992) or the production in the North (*e.g.*, Grossman and Helpman, 1991a, Ch. 12) influencing the monopoly duration. $I_N(j,t)$ is given by:

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[21] There are different scenarios of drastic innovations in the literature (for example, the General Purpose Technologies, usually christened GPT) but, in the present work, we will not discuss these.

$$I_N(j,t) = y_N(j,t)\beta_N q^{k_N(j,t)} {\zeta_N}^{-1} q^{-\alpha^{-1}k_N(j,t)}, \tag{3.9}$$

where $y_N(j,t)$ is the flow of final good resources in the North allocated to R&D in j, which defines our setup as a lab equipment model (*e.g.*, Rivera-Batiz and Romer, 1991); $\beta_N q^{k_N(j,t)}$ (with $\beta_N > 0$) denotes learning by previous domestic R&D, as a positive learning effect of accumulated public knowledge from earlier successful R&D (*e.g.*, Grossman and Helpman, 1991a, Ch. 12; Connolly, 2003); ${\zeta_N}^{-1} q^{-\alpha^{-1}k_N(j,t)}$ (with $\zeta_N > 0$) is the adverse effect (cost of complexity) caused by the rising complexity of quality upgrades (*e.g.*, Kortum, 1993, 1997; Dinopoulos and Segerstrom, 2007).[22]

Since the South is less developed, though not by too great a margin, we consider that there are intermediate goods for which $k_S < k_N$, implying that there are a number of top qualities produced in both countries even without international trade (*i.e.*, for which $k_S = k_N$). The existence of international trade allows the South to gain access to all the best qualities so that it becomes an imitator, increasing the instantaneous probability of successful imitation of the top quality $k_N(j,t)$ in j, $I_S(j,t)$, given by

$$I_S(j,t) = \; y_S(j,t)\beta_S q^{k_S(j,t)} \frac{e^{\varphi}}{\zeta_S \tilde{Q}^{\sigma}} q^{-\frac{k_N(j,t)}{\alpha}} \frac{1}{\delta}\left(\frac{1}{\tilde{Q}}\right)^{1-\delta}$$

$$= y_S(j,t)\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}}, \tag{3.10}$$

where $y_S(j,t)$ represents the flow of domestic final good resources allocated to R&D in intermediate good j, $\beta_S q^{k_S(j,t)}$ denotes the learning-by-past imitations (and we assume

[22] As will become clear later on, the technical reason for the existence of the production function parameter α in equation (3.9) is the complexity cost, which along with the positive learning effect exactly balances the positive influence of the quality rung on the profits of each top intermediate good firm. In this sense, β_N reflects a positive spillover effect from past experience and ζ_N is a fixed cost of innovative research.

that $0 < \beta_S < \beta_N$ and $k_S < k_N$, *i.e.*, we consider that the learning-by-past imitations is lower than the learning-by-past innovations). In a similar way, according to the empirical findings of Mansfield *et al.* (1981), the fixed cost of imitation ζ_S is supposed to be smaller than the innovation cost ζ_N. In line with Connolly and Valderrama (2005), the cost of imitation $\frac{\zeta_S \tilde{Q}^{\sigma}}{e^{\varphi}}$ is affected by two new factors. Firstly, it depends positively on the sector j South/North technology ratio $\hat{q}_j$, and indicates the increasing cost of imitation as Southern technology approaches Northern technology. Therefore, there are decreasing returns to imitation since the group of goods that can be selected for imitation diminishes. In this context, σ influences the speed with which the cost of imitation increases as the technology gap drops.[23] Secondly, the cost depends negatively on the interaction between the two countries, φ. This is quantified by the South's openness to imports of intermediate goods, *M*, scaled by the aggregate Northern technological level, $Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}$. Once the imitation cost increases and the technology gap between North and South decreases, both the probability of imitation and the probability of innovation are modified during transition towards the steady state.

Also in equation (3.10), $\delta \in [0,1]$measures the degree of IPR enforcement in the South,[24] $\varphi = \left(\frac{M}{Q_N}\right)^{\eta}$ and $\tilde{Q} = \frac{q^{k_S(j,t)*J}}{q^{k_N(j,t)*J}} = \frac{QS}{QN} = \hat{q}_j$ (with $0 < \tilde{Q} < 1$). Hence, we fix a negative relationship between δ and $I_S(j,t)$: the greater the parameter δ, the greater the degree of IPR enforcement in the South and the smaller the probability of successful

[23] Once the experience obtained from imitation rises one-to-one with $\hat{q}$, σ has to be greater than 1 for the probability of imitation to decrease as $\hat{q}$ rises. This assures a smooth transition.

[24] As stressed previously, we intend to understand in what form IPR should be treated in an endogenous growth model but there is no a consensus in the literature about the best way to introduce IPR in a model. However, the most part of literature argues that IPR make imitation harder and then, we establish a negative relation between IPR and imitation.

imitation. Moreover, we consider that the smaller is the distance to the technological frontier (the higher $\tilde{Q}$) the more these countries will implement IPR laws.

In general, developed countries have higher levels of IPR protection (*e.g.*, Lai and Qiu, 2003; Grossman and Lai, 2004; Naghavi, 2007; Dinopoulos and Segerstrom, 2010). Nevertheless, it seems that in future research it will be necessary to verify whether the North has implemented IPR laws more or less rigorously compared with the South, since some other issues emerge from this discussion. For instance, it is interesting to analyse the causality effects that may here be involved: are developing economies less developed because they have weaker institutions, which also implies inability to apply stronger enforcement of IPR laws, or do these less developed countries fix a low level of protection, having also a low enforcement of IPR laws, because they intend to stimulate imitation in order to grow faster? We should bear in mind that some studies state that the relationship between the degree of IPR and innovation is not linear: it has an inverted U-shape (*e.g.*, Furukawa, 2007, 2010; Panagopoulos, 2009).

Following this line of reasoning, Kim *et al*. (2012) empirically study not only the importance of the strength of IPR, but also the type of IPR suitable for distinct levels of economic development. The main conclusion of this study is that patent protection influences R&D intensity, and thus affects economic growth. Moreover, the results show that patent protection improves innovation (and hence economic growth) in countries where there is the capacity to develop innovative R&D. Thus, according to Kim *et al*. (2012), on the one hand R&D has a positive effect on economic growth in high income countries and in those middle income countries that use intellectual property protection to reward imitative and adaptive R&D, while on the other hand petty patents or utility models are positively linked with the R&D intensity of middle to low income countries.

The results of Xu and Chiang (2005) state that high income countries enjoy both internal technology and foreign technology, which is included in imported capital goods, whereas middle income countries benefit from technology spillovers from both foreign patents and imported capital goods. Finally, low income countries receive essential benefits from foreign patents. Moreover, they conclude that government policies regarding IPR protection and trade openness have significant effects on foreign technology spillovers in middle income and poor nations. In undertaking this study, the authors use the index of patent rights constructed by Ginarte and Park (1997), (whose value varies from zero to five, where zero is the weakest and five is the strongest value), as the measure of IPR and we can verify that, in the sample, the US – North – has the highest value of IPR (4.55), while Indonesia – South – has the lowest (0.64). If we place the values in ascending order, it is possible to confirm that in general Southern countries have lower levels of IPR protection, whereas Northern countries have higher levels.

3.2.4. Consumers

We assume that the Northern consumer makes consumption and savings decisions so that he/she can maximize the present value lifetime utility:[25]

$$\max_{\{C_N, C_S^*, a\}t\to\infty} \int_0^\infty u(\bar{C}_N) e^{-\rho t}\, dt \qquad (3.11)$$

[25] Note that the model is not without drawbacks since we consider some assumptions, similarly to Afonso (2012), that simplify the model. However, we believe they do not affect significantly the conclusions because these issues are not in discussion in the present work. We can underline two of these unrealistic assumptions: infinitely-lively agents maximize lifetime utility and full employment of labour both in the North and in the South.

$$u(\bar{C}_N) = \left(\frac{\bar{C}_N^{1-\theta} - 1}{1-\theta}\right) \tag{3.12}$$

$$\bar{C}_N = C_N^{k} C_S^{f\,1-k} \tag{3.13}$$

$$\dot{a}_N = r_N a_N + w_N - E_N \tag{3.14}$$

$$E_N = P_N C_N + P_S^f C_S^f \tag{3.15}$$

$u(\bar{C}_N)$ is the instantaneous utility function with a constant intertemporal elasticity of substitution (CIES), where $\bar{C}_N$ is the Northern composite good, θ defines the inverse intertemporal elasticity of substitution and $\rho > 0$ is the homogeneous subjective discount rate.

Equation (3.13) is a Cobb-Douglas aggregator that describes the Northern composite good, $\bar{C}_N$, in terms of Northern and Southern final goods, C_N and C_S^f, respectively, both consumed in the North (f means foreign or exports). In the same equation, parameter k corresponds to domestic expenditure-share.

The return to assets, a_N, in the North is r_N, and the wage rate is w_N. One unit of labour is supplied inelastically during every period. The path of the value of assets, $\dot{a}_N$, is represented in equation (3.14) as being the difference of labour and interest income minus Northern consumption expenditures, E_N (the budget constraint that is expressed as savings=income–consumption). The total Northern expenditures, E_N, are described in equation (3.15).

As in Connolly and Valderrama (2005), and Obstfeld and Rogoff (1996), the consumption-based price index, $\bar{P}_N$, is characterized as the minimum expenditure, E_N, so that the composite good index, $\bar{C}_N = 1$, for a given set of prices:

$$\bar{P}_N = \left(\frac{P_N}{k}\right)^{k} \left(\frac{P_S^f}{1-k}\right)^{1-k} \tag{3.16}$$

From standard calculations, we obtain two expressions for consumer demands:

$$C_N = \mathscr{k} \frac{\bar{P}_N}{P_N} \bar{C}_N \tag{3.17}$$

$$C_S^f = (1 - \mathscr{k}) \frac{\bar{P}_N}{P_S^f} \bar{C}_N \tag{3.18}$$

If we transfer these expressions to the household utility maximization problem, we arrive at the usual expression for consumption growth (the standard Euler equation):

$$\frac{\dot{\bar{C}}_N}{\bar{C}_N} = \hat{\bar{C}}_N = \frac{1}{\theta}\left(r_N - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right) \tag{3.19}$$

The problem of the Southern consumer is absolutely symmetric:

$$\max_{\{C_N^*, C_S, a\} t \to \infty} \int_0^\infty u(\bar{C}_S) e^{-\rho t}\, dt \tag{3.20}$$

$$u(\bar{C}_S) = \left(\frac{\bar{C}_S^{1-\theta} - 1}{1 - \theta}\right) \tag{3.21}$$

$$\bar{C}_S = C_N^{f\,1-\mathscr{b}} C_S^{\mathscr{b}} \tag{3.22}$$

$$\dot{a}_S = r_S a_S + w_S - E_S \tag{3.23}$$

$$E_S = P_S C_S + P_N^f C_N^f \tag{3.24}$$

Assuming that both countries spend the same income share on the goods produced in the North, $\mathscr{b} = 1 - \mathscr{k}$, the resulting expression for the Southern households' demand is:

$$\bar{P}_S = \left(\frac{P_N^f}{\mathscr{k}}\right)^{(\mathscr{k})} \left(\frac{P_S}{1 - \mathscr{k}}\right)^{(1-\mathscr{k})} \tag{3.25}$$

$$C_N^f = \mathscr{k} \frac{\bar{P}_S}{P_N^f} \bar{C}_S \tag{3.26}$$

$$C_S = (1 - \mathscr{k}) \frac{\bar{P}_S}{P_S} \bar{C}_S \tag{3.27}$$

Additionally, hypothetically, the relative price of the South's final good always adjusts to balance trade:

$$P_S = \frac{P_N\left(1 + \tau_{Y_S}\right) C_N^f + P_{NS}^f n_{NS} X_{NS}^f + P_{NN}^f n_{NN} X_{NN}^f - P_{NS}^f n_{NS} X_S^f}{\left(1 + \tau_{Y_N}\right) C_S^f} \tag{3.28}$$

3.3. General Equilibrium

After describing the countries' structures in our modelling setup, we go on to compute the equilibrium dynamics of technological knowledge which is responsible for economic growth in cases where neither labour nor human capital accumulation exist. The effects caused by the interaction between the North and South, deriving from international trade of intermediate goods, occupy an important position in the dynamics general equilibrium.

The dynamic general equilibrium, and thus the particular case of the steady state, is defined by the path of resources allocation and prices, such that: (i) consumers and firms solve their problems; (ii) R&D free-entry conditions are met; and (iii) markets clear.

3.3.1. Equilibrium R&D

The expected current value of the flow of profits to the producer of j, $V(k,j,t)$,[26] relies on the profits at t, $\Pi_S(k,j,t)$, on the equilibrium interest rate and on the expected duration of the flow (*i.e.*, expected duration of research leadership). $\Pi_S(k,j,t)$ depends on $MC_N = 1$, MC_S, $P_{NN}(j)$, $P_{NS}(j)$, $x_N(k,j,t)$ and $x_S(k,j,t)$ and thus on trade. For example, the expected duration of the imitator's leadership depends on $I_N(k,j,t)$, which is the potential challenger, since the Southern entrant competes with a Northern incumbent. Thus, $V_S(k,j,t)$ is:

$$V_S(k,\bar{j},t) = \int_t^{\infty} \Pi_S(k,\bar{j},t)\, exp\left[-\int_t^{s} (r_S(v) + I_N(k,\bar{j},v))dv\right] ds \tag{3.29}$$

where $\Pi_S(k,j,t)$ using an imitation of the top quality k is:

[26] *I.e.*, *V*(*k*, *j*, *t*) is the market value of the patent or the value of the monopolist firm, owned by consumers.

$$\Pi_S(k,\bar{j},t) = (1-\alpha)^{\alpha^{-1}} q^{k_N(j,t)(1-\alpha)\alpha^{-1}} \left[(1-MC_S)L_N(t){A_N}^{\alpha^{-1}} + (1+\tau_{x_S} - MC_S)L_S(t)\left(A_S \frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}} \right] \quad (3.30)$$

Differentiating equation (3.29) using Leibniz's rule, we obtain the dynamic arbitrage equation:

$$r_S(v) + I_N(k,\bar{j},v) = \frac{\dot{V}_S(k,\bar{j},t)}{V_S(k,\bar{j},t)} + \frac{\Pi_S(k,\bar{j},t)}{V_S(k,\bar{j},t)} - \dot{k}(\bar{j},t)\left(\frac{1-\alpha}{\alpha}\right) ln\, q \quad (3.31)$$

Plugging equation (3.31) into the free entry R&D equilibrium condition, $I_S(j,t)V_S(j,t) = y_S(j,t)$, and solving it for I_N, we obtain the equilibrium probability of successful innovation. Since the probability of successful innovation drives the technological knowledge progress, equilibrium can be transferred to the path of Northern technological knowledge, from which free trade in intermediate goods also allows the South to benefit. The relationship turns out to yield the well-known expression for the equilibrium growth rate of Q_N:

$$\hat{Q}_N = I_N\left(q^{(1-\alpha)\alpha^{-1}} - 1\right). \quad (3.32)$$

3.3.2. Steady state

Bearing in mind Afonso (2012), we assume that, as both economies have access to the same technology of final goods production and to the same state-of-the-art intermediate goods through free trade, the steady state growth rate is also the same. This means that, through Euler equation (3.19), the steady state interest rates are equal in both economies.

Additionally, following the same contribution, we consider that the instantaneous aggregate resources constraint in the South, for instance, is $Y_S(t) = \bar{C}_S(t) + X_S(t) + R_S(t)$, where $Y_S(t)$ represents total resources, the composite final good; $\bar{C}_S(t)$ denotes aggregate consumption; $X_S(t)$ is aggregate intermediate goods; $R_S(t)$ refers to total resources employed in R&D. That is, the aggregate final good is used for consumption, production of intermediate goods and R&D. So the steady state is characterised by constant growth, g^*, common to both countries, and is driven by available (Northern) technological knowledge progress (whose steady state growth rate is equal to the steady state growth rates of each variables),

$$g^* = \hat{Q}_N^* = \hat{Y}_N^* = \hat{Y}_S^* = \hat{X}_N^* = \hat{X}_S^* = \hat{R}_N^* = \hat{R}_S^* = \hat{\hat{C}}_S{}^* = \hat{\hat{C}}_N{}^* = \frac{1}{\theta}(r^* - \rho) \qquad (3.33)$$

$\Rightarrow$ in particular $\hat{\tilde{Q}}^* = 0$ and sector shares n_{NN}, n_{NS} and n_S will be constant.[27]

Hence, the steady state growth rates of both countries depend exclusively on Northern technological progress, while the North remains the lead innovating country. Additionally, international trade and the succeeding risk of losing the market for a certain intermediate good to Southern imitation implies that the Northern rate of innovation depends on the Southern rate of imitation.

In steady state, $\frac{\dot{V}_S(k,\bar{j},t)}{V_S(k,\bar{j},t)} = \dot{k}(\bar{j},t)\left(\frac{1-\alpha}{\alpha}\right)\ln q$ and thus, bearing in mind equation (3.10), equation (3.31) becomes:

$$I_N^* = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1 - MC_S) L_N{}^* A_N{}^{\alpha^{-1}} + \left(1 + \tau_{x_S} - MC_S\right) L_S{}^* \left(A_S \frac{MC_S}{1 + \tau_{x_S}} \right)^{\alpha^{-1}} \right] - r^* \qquad (3.34)$$

Equation (3.34) shows that the available (or Northern) technological knowledge progress:

(i) hinges on the returns to innovation, which in turn rely on terms of I_S, $\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma}$, through inter country competition in intermediate goods. That is, the positive level effect from *N* to *S* (the access to the top quality intermediate goods increases production and thus the resources to imitative R&D) feeds back into *N*, affecting Q_N by creative destruction;

[27] Moreover, from the entry-exit conditions, equations (3.8a)-(3.8c), it is possible to obtain the expressions for the steady state decomposition of intermediate goods sectors into these three categories (see Appendix A.2.).

(ii) is independent of its scale, since it is not affected by the rung of quality k. Indeed, the positive influence of the quality rung on profits and on the learning effect is exactly offset by the negative influence on the complexity cost;[28]

(iii) is dependent on the market size effects.

Taking into account equations (3.32), (3.33) and (3.34), we can reach the steady state interest rate: firstly, we put equation (3.34) into equation (3.32) in replacing I_N, secondly we use equation (3.33) into the obtained equation replacing $\hat{Q}_N^*$ and finally we solve this in order to r^*. Indeed, since steady state prices of non-tradable and tradable goods are constant as well as the growth rate of available technological knowledge, see equations (3.32) and (3.34), the common steady state interest rate, r^*, is obtained:

$$r^* = \frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1-MC_S) {L_N}^* {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) {L_S}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]\right\} \left(q^{(1-\alpha)\alpha^{-1}} - 1\right) + \frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}} - 1 + \frac{1}{\theta}} \quad (3.35)$$

Now, we can easily achieve the steady state growth rate by using the previous expression in the Euler equation (3.19):

$$g^* = \frac{1}{\theta}\left[\left(\frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1-MC_S) {L_N}^* {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) {L_S}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]\right\} \left(q^{(1-\alpha)\alpha^{-1}} - 1\right) + \frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}} - 1 + \frac{1}{\theta}}\right) - \rho\right] \quad (3.36)$$

The common steady state growth rates imply the persistence of a steady state North-South gap in technological knowledge. While total convergence in available technological knowledge is immediate with international trade (level effect), domestic levels may not converge totally; *i.e.*, Q_N^* may stay below one.

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[28] This is crucial for a symmetric equilibrium (on asymmetric equilibrium in quality ladder models and its growth consequences, see Cozzi *et al.*, 2007).

While evaluation of equation (3.35) or equation (3.36) requires solving for transitional dynamics through calibration and simulation, we can, however, emphasize six ways, in addition to the level effects, through which the trade influences, in opposite directions, steady state growth.

The first way in which trade influences steady state growth is the positive catching-up effect on the probability of successful imitation. The advantages of backwardness are only obtained in the presence of trade. Through the feedback effect, the probability of successful innovation is also affected and thus the steady state growth rate.

The second way is the positive spillovers from the North to the South. Each innovation in the North tends to lower the cost of imitation by the South because the backwardness advantage is strengthened with each improvement of the technological-knowledge frontier.

The third way is the positive effect arising from market enlargement, which encourages R&D activities by effecting the respective profitability.

The fourth (counteracting) channel is the monopolistic competition mark-up. The monopolist in the North loses profits with the entry into trade: the average mark-up is smaller under trade. The reason for this is that in pre-trade successful innovators are protected from international competition. Once engaged in trade and imitation becomes profitable, profit margins in the North are reduced, which discourages R&D activities.

The fifth way through which trade affects steady state growth, counteracting as well, is that firms in the South have to support the R&D cost of state-of-the-art intermediate goods, possibly several quality rungs above (and thus more complex) their own experience level in pre-trade.

The sixth way through which trade affects steady state growth, also counteracting, is by IPR; *i.e.*, by increasing the IPR enforcement, the steady state growth rate decreases. In terms of steady state comparative static, and differentiating (3.36) with respect to IPR parameter (δ), we achieve $-\frac{e^{\varphi}\zeta_S}{(\zeta_S\delta)^2}+\frac{e^{\varphi}}{\zeta_S\delta}\ln\tilde{Q}^*<0, \tilde{Q}^{*\,\delta-\sigma}\left(-\frac{e^{\varphi}\zeta_S}{(\zeta_S\delta)^2}+\frac{e^{\varphi}}{\zeta_S\delta}\ln\tilde{Q}^*\right)<0$ and thus $\frac{\partial g^*}{\partial\delta}<0$. The rise in IPR makes imitation costly in the South, and as a result the probability of successful imitation decreases. Through the feedback effect, this rise also has a negative effect on the steady state probability of innovation, which supports the literature that argues that the IPR effect on economic growth is not always positive.

Moreover, as we have discussed above, this effect can be ambiguous. On the one hand, there are studies that argue for a positive relationship between IPR enforcement and economic growth (see for instance Falvey *et al*., 2009, and Chu *et al*., 2012), while others present a negative one, a result dependent on certain features or even an inconclusive result (see, *e.g.*, Datta and Mohtadi, 2006; Horii and Iwaisako, 2007; Furukawa, 2010). On the other hand, in general, empirical evidence suggests a positive effect of IPR on economic growth (see Azevedo *et al.*, 2012). However, this evidence can be justified by the empirical measure of patent protection most commonly used (*e.g.*, Chu, 2009b).

In this sense, we can say that the result is still pending. In the next section we will present the main conclusions of the chapter and discuss the possibility of following some research avenues in the future.

3.4. Concluding remarks

The relationship between IPR and economic growth (or innovation) has been increasingly analysed in recent years, and IPR have become a common field of discussion in the literature relating to economic growth. However, the existing literature presents different results regarding the effect of IPR on economic growth, and some studies present distinct results under some constraints. Hence, we can conclude that this link is not clear.

In this chapter, we have emphasized the importance of analysing IPR within an endogenous growth theoretical framework. Using as our motivation a brief account of the development of IPR literature, we have analysed the most commonly used mechanisms for introducing IPR into a model in an effort to better understand the connection between IPR and economic growth. Our general equilibrium endogenous growth model considers an IPR parameter in the function of the probability of imitation. We have also checked the sign of the effect of IPR enforcement on economic growth and have discussed the differences between our result and those reported in the related literature.

In particular, by introducing the IPR parameter into the probability of imitation function, we have made imitation more difficult; *i.e.*, we have reduced the probability of imitation. Additionally, in the same function, we have introduced a negative relationship between the distance of each country from the technology frontier and IPR enforcement. This distance had a positive effect on the probability of successful imitation because the higher the distance of the country from the technology frontier (*i.e.*, the lower is $\tilde{Q}$), the higher the probability of imitation, I_S. In the end, we found that IPR enforcement impacted negatively on the steady state growth rate.

Our main result is not in line with the most common results concerning the empirical evidence on the topic (see Azevedo *et al.*, 2012). However, the existing literature is not consensual as regards the IPR effect on economic growth.

In this context, it should be stressed that our aim in this chapter is not to impose the true sign of the relationship between IPR and economic growth but to develop an endogenous growth model in which IPR are introduced and in which they play a central role in the analysis.

This analysis suggests that there is much more work to be done in this field. In future research, it would be interesting to analyse, for example, the nature of the sign found differentiating (3.36) with respect to IPR parameter (δ), because it can actually rely on countries' development level. Hence, it would also be useful to discuss the different degrees of IPR protection according to the countries' levels of development. The main argument supporting this idea is that each country, according to its stage of development, can have different necessities of innovation and imitation, so it will also have different needs in terms of IPR protection.

Another interesting study for future investigation is to verify whether, in countries where IPR laws do exist, they are strictly/effectively enforced, because afterwards it will be easier to understand the way in which the causality between IPR enforcement and economic development occurs. It will be easier to investigate whether these countries are less developed since they abide more strictly the IPR laws, or whether on the contrary these countries do not adhere to IPR laws (for instance, because their institutions are weaker) or arrange a low level of protection to imitate the others in order to achieve more development. However, the latter case may lead to the opposite result and may be a possible cause of sluggish development in those countries which lag behind. Hence, it would be useful to ascertain what kind of countries most respect IPR enforcement.

Appendix A

A.1. Solving the model

Starting from the production function, $Y_i(t) = A_i L_i{}^{\alpha} \sum_{j=1}^{J} \left(q^{k_N(j,t)} x_i(j,t)\right)^{1-\alpha}$, and differentiating it in order to $x_i(j,t)$ yields

$$\frac{\partial Y_i(t)}{\partial x_i(j,t)} = A_i(1-\alpha) L_i{}^{\alpha} q^{k_N(j,t)(1-\alpha)} x_i(j,t)^{-\alpha}.$$

If we define the profit of a final goods producer as

$$\pi_i = p_i(t)Y_i(t) - w_i L_i - \sum_{j=1}^{N} p(j,t) x_i(j,t),$$

each final goods firm solves the following maximization problem and respective first order condition (FOC):

$$\max_{x_i(j,t)} \pi_i \Rightarrow \frac{\partial \pi_i}{\partial x_i(j,t)} = 0$$

$$(=) \frac{\partial\left[p_i(t)Y_i(t) - wL_i - \sum_{j=1}^{N} p(j,t) x_i(j,t)\right]}{\partial x_i(j,t)} = 0$$

$$(=) A_i(1-\alpha) L_i{}^{\alpha} q^{k_N(j,t)(1-\alpha)} x_i(j,t)^{-\alpha} = \frac{p(j,t)}{p_i(t)}.$$

Solving the previous expression in order to $x_i(j,t)$, we obtain the equation for the implicit demand for each j by the representative producer of i^{th} final good:

$$x_i(j,t) = L_i \left[A_i(1-\alpha)\frac{p_i(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}.$$

Putting the previous expression into the production function and replacing the prices, we obtain the supply of final good in each country, respectively:

(i) for the North,

$$Y_N(t) = A_N L_N^{\alpha} \sum_{j=1}^{J} \left(q^{k_N(j,t)} L_N \left[A_N(1-\alpha)\frac{p_N(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_{Nj}(j,t)\left[\frac{1-\alpha}{\alpha}\right]} \right)^{1-\alpha}$$

$$(=) Y_N(t) = A_N L_N^{\alpha} L_N^{1-\alpha} A_N^{\frac{1-\alpha}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \sum_{j=1}^{J} \left(q^{k_N(j,t)(1-\alpha)} q^{k_N(j,t)\frac{(1-\alpha)^2}{\alpha}} \right) \left(\frac{p_N(t)}{p(j,t)}\right)^{\frac{1-\alpha}{\alpha}}$$

$$(=) Y_N(t) = Q_N L_N A_N^{\frac{1}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \left[\left(\frac{MC_N}{qMC_N}\right)^{\frac{1-\alpha}{\alpha}} n_{NN} + \left(\frac{MC_N}{qMC_S(1+\tau_{x_S})}\right)^{\frac{1-\alpha}{\alpha}} n_{NS} + \left(\frac{MC_N}{1}\right)^{\frac{1-\alpha}{\alpha}} n_S \right]$$

$$(=)Y_N(t) = \; Q_N L_N A_N^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} \; \left[n_{NN} + n_{NS} MC_S^{\frac{\alpha-1}{\alpha}}(1+\tau_{x_S})^{\frac{\alpha-1}{\alpha}} + n_S q^{\frac{1-\alpha}{\alpha}}\right];$$

(ii) for the South:

$$Y_S(t) = A_S L_S^{\alpha} \sum_{j=1}^{J} \left(q^{k_N(j,t)} L_S \left[A_S(1-\alpha)\frac{p_S(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left[\frac{1-\alpha}{\alpha}\right]} \right)^{1-\alpha}$$

$$(=)Y_S(t) = A_S L_S^{\alpha} L_S^{1-\alpha} A_N^{\frac{1-\alpha}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \sum_{j=1}^{J} \left(q^{k_N(j,t)(1-\alpha)} q^{k_N(j,t)\frac{(1-\alpha)^2}{\alpha}} \right) \left(\frac{p_S(t)}{p(j,t)}\right)^{\frac{1-\alpha}{\alpha}}$$

$$(=)Y_S(t) = \; Q_S L_S A_S^{\frac{1}{\alpha}} (1-\alpha)^{\frac{1-\alpha}{\alpha}} \left[\left(\frac{MC_S}{q(1+\tau_{x_S})}\right)^{\frac{1-\alpha}{\alpha}} n_{NN} + \left(\frac{MC_S}{qMC_S}\right)^{\frac{1-\alpha}{\alpha}} n_{NS} + \left(\frac{MC_S}{(1+\tau_{x_S})}\right)^{\frac{1-\alpha}{\alpha}} n_S \right]$$

$$(=)Y_S(t) = \; Q_S L_S A_S^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} \left[n_{NN} \left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}} + n_{NS} + n_S q^{\frac{1-\alpha}{\alpha}} \left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}} \right].$$

The monopolist profit can be described by $\Pi\big(k_N(j,t)\big) = (p(j,t) - MC)x_i(j,t)$. Assuming that $MC_i = P_{Y_i}$, $MC_N = 1$ and $MC_N > MC_S$ we can write the profit of the Northern monopolist intermediate goods firm as

$$\Pi\big(k_N(j,t)\big) = (p(j,t) - 1)x_N(j,t)$$

$$(=)\Pi\big(k_N(j,t)\big) = (p(j,t) - 1)L_N \left[A(1-\alpha)\frac{p_N(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}.$$

Then, we can describe their maximization problem and the respective FOC as

$$\max_{p(j,t)} \Pi\big(k_N(j,t)\big) \Rightarrow \frac{\partial \Pi\big(k_N(j,t)\big)}{\partial p(j,t)} = 0$$

$$(=)\frac{\partial (p(j,t) - 1)L_N \left[A(1-\alpha)\frac{p_N(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}}{\partial p(j,t)} = 0$$

$$(=)p(j,t) = \frac{1}{1-\alpha}.$$

When $q \leq \frac{1}{1-\alpha}$, firms use limit pricing rather than monopoly pricing, $P_S^f = 1$ and $P_S = 1 + \tau_{x_S}$ in the Southern case, the profit of the Southern monopolist intermediate goods firm is given by

$$\Pi_S(k,j,t) = (p(j,t) - MC_S)x_i(j,t).$$

$$(=)\mathit{\Pi}_S(k,j,t) = \left(P_S^f - MC_S\right)x_N(j,t) + (P_S - MC_S)x_S(j,t)$$

$$(=)\mathit{\Pi}_S(k,j,t) = \left(P_S^f - MC_S\right)L_N\left[A_N(1-\alpha)\frac{p_N(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}$$

$$+ (P_S - MC_S)L_S\left[A_S(1-\alpha)\frac{p_S(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}$$

$$(=)\mathit{\Pi}_S(k,j,t) = \left(P_S^f - MC_S\right)L_N\left[A_N(1-\alpha)\frac{MC_N}{P_S^f}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)} + (P_S - MC_S)L_S\left[A_S(1-\alpha)\frac{MC_S}{P_S}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}$$

$$(=)\mathit{\Pi}_S(k,j,t) = (1-\alpha)^{-\alpha} q^{k_N(j,t)\left(\frac{1-\alpha}{\alpha}\right)}\left[(1-MC_S)L_N {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right)L_S\left(A_S\frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right].$$

We assume that the expected current value of the flow of profits to the producer of j is given by

$$V_S(k,\bar{\jmath},t) = \int_t^{\infty} \mathit{\Pi}_S(k,\bar{\jmath},t)\, exp\left[-\int_t^s (r_S(v) + I_N(k,\bar{\jmath},v))dv\right]ds,$$

and if we differentiate the previous expression using the Leibniz's rule, we obtain the dynamic arbitrage equation:

$$r_S(v) + I_N(k,\bar{\jmath},v) = \frac{\dot{V}_S(k,\bar{\jmath},t)}{V_S(k,\bar{\jmath},t)} + \frac{\mathit{\Pi}_S(k,\bar{\jmath},t)}{V_S(k,\bar{\jmath},t)} - \dot{k}(\bar{\jmath},t)\left(\frac{1-\alpha}{\alpha}\right) ln\, q.$$

As, in steady state, $\frac{\dot{V}_S(k,\bar{\jmath},t)}{V_S(k,\bar{\jmath},t)} = \dot{k}(\bar{\jmath},t)\left(\frac{1-\alpha}{\alpha}\right)\ln q$,

$$r_S(v) + I_N(k,\bar{\jmath},v) = \frac{\mathit{\Pi}_S(k,\bar{\jmath},t)}{V_S(k,\bar{\jmath},t)}$$

$$(=)V_S(k,\bar{\jmath},t) = \frac{\mathit{\Pi}_S(k,\bar{\jmath},t)}{r_S(v) + I_N(k,\bar{\jmath},v)}$$

Moreover, as $I_S(j,t)V_S(j,t) = y_S(j,t)$,

$$y_S(j,t)\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{\delta-\sigma}q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}}V_S(j,t) = y_S(j,t)$$

$$(=)y_S(j,t)\left[\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{\delta-\sigma}q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}}V_S(j,t) - 1\right] = 0.$$

Considering that $y_S(j,t) > 0$, for the previous expression to be true implies that

$$\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{\delta-\sigma}q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}}V_S(j,t) - 1 = 0.$$

Taking into account the previous equation and the expressions for $V_S(k,\bar{\jmath},t)$, $\mathit{\Pi}_S(k,\bar{\jmath},t)$ and $I_N(k,\bar{\jmath},v)$,

$$\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}} V_S(j,t) = 1$$

$$(=)\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}} \frac{\Pi_S(k,\bar{j},t)}{r_S(v) + I_N(k,\bar{j},v)} = 1$$

$$(=)\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}} \Pi_S(k,\bar{j},t) = r_S(v) + I_N(k,\bar{j},v)$$

$$(=)\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} (1-\alpha)^{-\alpha} \left[(1-MC_S) L_N {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) L_S \left(A_S \frac{MC_S}{1+\tau_{x_S}} \right)^{\alpha^{-1}} \right] = r_S(v) + I_N(k,\bar{j},v)$$

$$(=)I_N(k,\bar{j},v) = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} (1-\alpha)^{-\alpha} \left[(1-MC_S) L_N {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) L_S \left(A_S \frac{MC_S}{1+\tau_{x_S}} \right)^{\alpha^{-1}} \right] - r_S(v),$$

in equilibrium,

$$I_N^* = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} {\tilde{Q}^*}^{\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1-MC_S) {L_N}^* {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) {L_S}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}} \right)^{\alpha^{-1}} \right] - r^*.$$

Moreover, knowing that the Northern aggregate quality index is described by $Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}$, we can obtain the well-known expression for the equilibrium growth rate of Q_N:

$$\Delta Q_N = \sum_{j=1}^{J} I_N(j,t) \left(q^{\frac{(k_N+1)(j,t)(1-\alpha)}{\alpha}} - q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}} \right)$$

$$(=)\Delta Q_N = I_N(j,t) \left[q^{\frac{(1-\alpha)}{\alpha}} - 1 \right] Q_N$$

$$(=)\frac{\Delta Q_N}{Q_N} = I_N(j,t) \left[q^{\frac{(1-\alpha)}{\alpha}} - 1 \right]$$

$$(=)\hat{Q}_N = I_N(j,t) \left[q^{\frac{(1-\alpha)}{\alpha}} - 1 \right].$$

Bearing in mind:

$\hat{Q}_N = I_N(j,t) \left[q^{\frac{(1-\alpha)}{\alpha}} - 1 \right]$,

$I_N^* = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} {\tilde{Q}^*}^{\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1-MC_S) {L_N}^* {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) {L_S}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}} \right)^{\alpha^{-1}} \right] - r^*$,

$g^* = \hat{Q}_N^* = \hat{Y}_N^* = \hat{Y}_S^* = \hat{X}_N^* = \hat{X}_S^* = \hat{R}_N^* = \hat{R}_S^* = \hat{C}_N^* = \hat{C}_S^* = \hat{c}^* = \frac{1}{\theta}(r^* - \rho)$ and

${\hat{Q}_N}^* = \left\{ \beta_S \frac{e^{\varphi}}{\zeta_S \delta} {\tilde{Q}^*}^{\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1-MC_S) {L_N}^* {A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right) {L_S}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}} \right)^{\alpha^{-1}} \right] - r^* \right\} \left(q^{\frac{(1-\alpha)}{\alpha}} - 1 \right)$ we have

$$\frac{1}{\theta}(r^*-\rho)=\left\{\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}}\left[(1-MC_S)L_N{}^*A_N{}^{\alpha^{-1}}+\left(1+\tau_{x_S}-MC_S\right)L_S{}^*\left(A_S\frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]-r^*\right\}\left(q^{\frac{(1-\alpha)}{\alpha}}-1\right)$$

$$(=)\left\{\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}}\left[(1-MC_S)L_N{}^*A_N{}^{\alpha^{-1}}+\left(1+\tau_{x_S}-MC_S\right)L_S{}^*\left(A_S\frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]-r^*\right\}\left(q^{\frac{(1-\alpha)}{\alpha}}-1\right)=\frac{1}{\theta}(r^*-\rho).$$

Solving it in order to r^*, we get the steady state interest rate common to both economies:

$$r^*=\frac{\left\{\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}}\left[(1-MC_S)L_N{}^*A_N{}^{\alpha^{-1}}+\left(1+\tau_{x_S}-MC_S\right)L_S{}^*\left(A_S\frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]\right\}\left(q^{(1-\alpha)\alpha^{-1}}-1\right)+\frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}}-1+\frac{1}{\theta}}.$$

Putting this equation into the Euler equation (3.19), we obtain the interest rate for both countries:

$$g^*=\frac{1}{\theta}\left[\left(\frac{\left\{\beta_S\frac{e^{\varphi}}{\zeta_S\delta}\tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}}\left[(1-MC_S)L_N{}^*A_N{}^{\alpha^{-1}}+\left(1+\tau_{x_S}-MC_S\right)L_S{}^*\left(A_S\frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right]\right\}\left(q^{(1-\alpha)\alpha^{-1}}-1\right)+\frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}}-1+\frac{1}{\theta}}\right)-\rho\right].$$

A.2. Steady-state decomposition of intermediate goods sectors into Northern firms facing Northern competition, n_{NN} , Northern firms challenging Southern competition, n_{NS}, and Southern firms, n_S

Given the exit-entry conditions, equations (3.8a)-(3.8c), and the steady state conditions, namely, the fact that, in steady state, n_{NN}, n_{NS} and n_S will be constant, *i.e.*, $\dot{n}_{NN}=\dot{n}_{NS}=\dot{n}_S=0$, we can obtain the decomposition of intermediate goods sector in each one of these three categories:

$$n_{NS}=\frac{n_{NN}}{(1-I_N)};$$

$$n_S=\frac{(1-\ I_N)J}{(2-I_N)};$$

$$n_{NN}=\frac{n_S}{(2-I_N)}.$$

Chapter 4

Economic growth and intellectual property rights: an empirical study

4.1. Overview

The importance of innovation to economic growth is commonly acknowledged in the literature (*e.g.*, Aghion and Howitt, 1992; Barro and Sala-i-Martin, 2004; Park, 2005; Falvey *et al*., 2006; Cozzi, 2009; Acemoglu and Akcigit, 2012). However, in theoretical terms, the role of Intellectual Property Rights (henceforth IPR) in this relationship is not clear.

Since innovation (technological knowledge) is partially non-excludable, domestic protection of IPR increases the domestic degree of excludability of the results of R&D. In turn, international enforcement of IPR, by protecting innovative R&D only, would prevent imitation R&D, and technological knowledge diffusion through this mechanism would be adversely affected. The relationship between IPR and economic growth may be analysed in two different ways: the IPR effect on economic growth and the impact of economic growth on the level of IPR protection. In the present work, we only focus on the first causality.

International IPR seem to be important to innovation and growth because, as devices to protect innovations, may operate as an incentive (*e.g*., Gould and Gruben, 1996; Glass and Saggi, 2002; Sener, 2006; Dinopoulos and Segerstrom, 2010) Nevertheless, the relationship between the degree of protection and innovation may be nonlinear; the IPR effect on economic growth is not necessarily positive and it may depend on the development level of countries (*e.g.,* Chen and Puttitanun, 2005; Furukawa, 2007; Chu, 2009b; Falvey *et al*., 2009). In the empirical literature it is frequent to find a positive and significant IPR effect on innovation and/or economic growth (*e.g.*, Chen and Puttitanun, 2005; Falvey *et* al., 2006), although this result is not always clear for both developed and developing countries.

Park and Ginarte (1997) provide a systematic study of how long-run economic growth is affected by patent protection. They highlight that although the existing literature clearly recognizes the importance of innovation for growth, only a small number of studies have empirically investigated the effects of institutions that stimulate innovation, namely those responsible for IPR. Recognizing the need of a quantitative measure for the intensity of IPR in each country, the authors construct an index of patent protection in 60 countries from 1960 to 1990, and use it to study the impact of IPR on economic growth.[29] They conclude that IPR affect economic growth indirectly by increasing Research and Development (R&D). Ginarte and Park (1997) construct the index for 110 countries and for the same time period, and use it to understand what are the main determinants regarding the protection strength of patent rights in these countries.

Park (2008) extends Ginarte and Park (1997), updating this study up to 2005 and enlarging the analysis to 122 countries. The indexes presented in Park and Ginarte (1997) and Ginarte and Park (1997) have been used by several other studies (*e.g.*, Versakelis, 2001; Kanwar and Evenson, 2003; Chen and Puttitanun, 2005; Xu and Chiang, 2005; Falvey *et al*., 2006; Groizard, 2009; Falvey *et al*., 2009).

Chen and Puttitanun (2005), studying 64 developing countries, estimate a positive effect of IPR on innovations and propose a U-shaped relationship concerning the relationship between IPR on economic development. Falvey *et al*. (2006) also conclude that the effect of IPR enforcement on growth depends on the level of development. More specifically, they show that IPR have a positive and significant effect on economic growth in low and high income countries, but not in middle income countries. Blind and Jungmittag (2008) analyse 4 European countries and 12 sectors, and estimate a more linear result, sustaining that the stocks of patents and of technical standards contributed significantly to economic growth in the 1990s.

Chu (2009b) emphasizes that, in order to analyse the effects of IPR enforcement on innovation, the majority of empirical works employ a cross-country regression analysis and measure national IPR protection as the index of patents constructed by Ginarte and Park (2007) and extended by Park (2008). Moreover, using an index or other type of measures, most empirical contributions on IPR use patents to measure IPR (*e.g.*, Azevedo *et al*., 2012).

Until 2000, as Park (2005) states, there was a small number of econometric works within this framework of analysis because, at that time, measures or indexes of patent

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[29] This index registers values from zero to five, where higher values denote stronger levels of protection, and it is constituted by five categories: coverage, membership in international patent agreements, provisions for loss of protection, enforcement mechanisms and duration (with each category assuming values from zero to one).

rights were relatively scarce. Additionally, empirical growth studies were not able to grade the influence of other kinds of IPR (for instance, copyrights and trade-marks) on growth because the available IPR indexes were commonly associated with patent rights. In order to overcome this gap, Park (2005) develops and includes indexes of other types of IPR and analyses their impact on productivity growth. More recently, Samaniego (2013) uses various property rights indicators such as patent enforcement, copyright enforcement, rule of law (which includes, for instance, trust in governmental institutions, perceptions of freedom from corruption) and a measure of physical property rights protection.

Moreover, most studies do not analyse directly the effect of IPR on economic growth. Rather, they study this relationship indirectly investigating, for example, the impact of IPR on R&D (*e.g.*, Versakelis, 2001), on innovation (*e.g.*, Chen and Puttitanun, 2005), on knowledge spillovers (*e.g.*, Samaniego, 2013) and on trade (*e.g.*, Falvey *et al*., 2009). Contributions such as Versakelis (2001) and Kanwar and Evenson (2003) find that the enforcement of patent protection has a positive impact on R&D intensity, which, in turns, has a positive effect on innovation. Kanwar and Evenson (2003), using the arguments related with weak and strong protection, discuss the potential distinct impact concerning development levels. For example, the authors point out that one of the benefits of weak IPR protection, particularly in developing countries, is the cheap purchase of technological knowledge through imitation. In what regards the advantages of strong IPR protection, the authors find evidence sustaining that it promotes innovation in more developed countries, namely in some industries such as pharmaceuticals and chemicals. Park (2005), using a sample of 41 nations, does not conclude that IPR stimulate productivity growth, but sustains that their enforcement promotes R&D activities. The author also stresses the differences between countries with distinct development levels, reinforcing the argumentation above by Kanwar and Evenson (2003).

Falvey *et al*. (2006) conclude that the positive impact of IPR enforcement on innovation also impinge positively on economic growth since the relationship between IPR protection and growth engages two effects: the effect of protection on innovation and the effect of innovation on economic growth. The authors argue that, for high income countries, the stronger their IPR protection, the faster their economic growth. In what regards low income countries, they stress that the positive relation between IPR and economic growth is not explained by the encouragement of domestic R&D and innovation, but rather is due to the fact that stronger IPR incentives imports and inward Foreign Direct Investment (FDI) from developed countries, without negatively influencing the internal industry of these countries, mostly dependent on imitation. Finally, concerning middle income countries, Falvey *et al.* (2006) find that IPR enforcement has not a significant effect on growth, which may result from two opposite effects: a positive one related with trade and inward FDI and a negative one connected with the slow diffusion of knowledge and the disincentive of imitation. Additionally, and in order to sustain the previous result, the authors point out that despite these countries do not usually innovate in significant terms, they have skills to perform imitation activities.

Alvi *et al*. (2007) also find a positive impact of patent protection on R&D, but the intensity of this relationship slows down when a specific threshold is achieved.

About the differences among countries, Park and Ginarte (1997) have earlier shown that stronger IPR protection increases economic growth. Moreover, although R&D has a positive impact on growth rates of both developed and developing countries, IPR are important for R&D activities in developed, but not in developing countries. The explanation for this result, according to the authors, is that a substantial part of the R&D sector in less developed countries is allocated to imitation and also that R&D efforts react here to different motivations (such as cultural rewards) when comparing with more developed countries. In this sense, these countries may be more interested in encouraging a stronger IPR protection as their economies develop and shift from imitative to innovative R&D.

In line with Ginarte and Park (1997), the vast majority of published empirical papers states that more developed countries tend to have stronger protection and the patent protection levels are influenced by the country’s level of R&D activity, market environment and international integration (which are connected with its development level). In particular, it seems that in order to increase the levels of patent’s protection in countries weakly protected, it is important to first promote a considerable research base.

A deep analysis of the major works about the empirics of IPR and economic growth highlights a lack of consensus on main results, which seems to be mostly associated with differences in the variable used to measure IPR, the structure of the data, the countries and time periods included in the samples and the estimation techniques.

Additionally, and as mentioned above, the majority of the empirical literature does not study the direct effect of IPR on economic growth. Hence, our main motivation with the present work is to analyse this relationship based on a model developed by Azevedo *et al.* (forthcoming), and to determine the IPR value associated with the steady state growth rate. We intend to empirically analyse this result, also checking for differences between countries with different development levels. We do not need to use any measure of IPR in the empirical analysis because we first estimate the value of the growth rate and only then obtain the value of IPR, using a two-step estimation procedure. From the second stage estimation, we gather the estimations of all variables and parameters.

The rest of the chapter is structured as follows. After this brief introduction, Section 4.2 presents a systematization of our previous modelling work that both offers the motivation for the present study and the needed theoretical framework. Section 4.3 details the empirical analysis. In Section 4.4, we present the obtained results. Finally, Section 4.5 concludes.

4.2. Theoretical baseline model: endogenous growth and IPR in a North-South model

In this section, we systematize our previous study (Azevedo *et al.*, forthcoming) that proposes a North-South model, with three sectors (the final goods sector, the intermediate goods sector and the R&D sector), and firms engaged in step-by-step innovation.

Relatively to the final goods sector, we consider the following production function:

$$Y_i(t) = A_i L_i^{\alpha} \sum_{j=1}^{J} \left(q^{k_N(j,t)} x_i(j,t)\right)^{1-\alpha}, \; i \in \{N, S\}, \tag{4.1}$$

where A_i is the exogenous productivity level which depends on each country's institutions such as government services, property law and tax law (A is higher in the North because we assume that institutions are better in the North), L_i is the labour input used in the production of the final good ($\alpha \in [0,1]$ is the labour share in the production), $q^{k_N(j,t)} x_i(j,t)$ is the quality adjusted intermediate good j at time t (we assume that $q(>1)$ expresses the size of each quality improvement achieved by each success in R&D, the steps of the quality ladder are represented by k and x is the quantity of j used along with labour to create the final good being that $(1-\alpha)$ is the aggregate intermediate goods input share). In each country, for a given price of the final good $(p_i(t))$ and of the intermediate good $(p(j,t))$, the implicit demand for each j by the representative producer of i^{th} final good is given by:

$$x_i(j,t) = L_i \left[A_i(1-\alpha)\frac{p_i(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left[\frac{1-\alpha}{\alpha}\right]}. \tag{4.2}$$

Replacing the price of final goods by the marginal costs and the price of intermediates by the limit prices (presented below) in equation (4.2), introducing it into equation (4.1) and after some mathematical manipulations, we obtain the supply of the final good in each country:

$$Y_N(t) = A_N^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_N Q_N \left[n_{NN} + n_{NS}\left(1+\tau_{x_S}\right)^{\frac{\alpha-1}{\alpha}} MC_S^{\frac{\alpha-1}{\alpha}} + n_S q^{\frac{1-\alpha}{\alpha}}\right], \tag{4.3}$$

$$Y_S(t) = A_S^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_S Q_N \left[n_{NN}\left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}} + n_{NS} + n_S q^{\frac{1-\alpha}{\alpha}}\left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}}\right], \tag{4.4}$$

$$Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}, \tag{4.5}$$

where τ_{x_S} represents the Southern tariffs on intermediates and *ad-valorem* transportation costs and MC denotes marginal cost .

With respect to the intermediate goods sector, we consider three kinds of firms: Northern firms facing Northern competition, n_{NN}, Northern firms facing Southern competition, n_{NS} , and Southern firms (imitators) which always face Northern competition, n_S. The sum of the weights associated to each type of firm is equal to J, the number of sectors. Moreover, we assume that each kind of firm fixes two limit prices, one for domestic sales and another for sales abroad; therefore, there are six limit prices: $P_{NN} = qMC_N = q$, $P_{NN}^f = q\left(1+\tau_{x_S}\right)$, $P_{NN}^f = q\left(1+\tau_{x_S}\right)$, $P_{NS}^f = qMC_S$, $P_S^f = 1$ and $P_S = 1+\tau_{x_S}$ (the prices with the index f represent the price in a foreign country).

For the R&D sector, it is important to underline the expressions for the probability of innovation and the probability of imitation, respectively:

$$I_N(j,t) = y_N(j,t)\beta_N q^{k_N(j,t)} {\zeta_N}^{-1} q^{-\alpha^{-1} k_N(j,t)}, \quad (4.6)$$

$$I_S(j,t) = y_S(j,t)\beta_S q^{k_S(j,t)} \frac{e^{\varphi}}{\zeta_S \tilde{Q}^{\sigma}} q^{-\frac{k_N(j,t)}{\alpha}} \frac{1}{\delta}\left(\frac{1}{\tilde{Q}}\right)^{1-\delta} = y_S(j,t)\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{\delta-\sigma} q^{k_N(j,t)\frac{(\alpha-1)}{\alpha}}. \quad (4.7)$$

Where $y_N(y_S)$ is the flow of final goods in the North (South) allocated to R&D in j, $\beta_N q^{k_N(j,t)}$ ($\beta_S q^{k_S(j,t)}$) denotes the learning-by-past innovation (imitation) - we assume that $\beta_N > \beta_S$ and $k_N > k_S$ because we consider that the learning-by-past innovations is higher than the learning-by-past imitations. ${\zeta_N}^{-1} q^{-\alpha^{-1} k_N(j,t)}$ is the adverse effect (the cost of complexity) caused by the rising complexity of quality upgrades. $\frac{e^{\varphi}}{\zeta_S \tilde{Q}^{\sigma}} q^{-\frac{k_N(j,t)}{\alpha}}$ represents the cost of imitation which depends not only on ζ_S (the fixed cost) but also on φ (the interaction between the two countries, which is equal to $\left(\frac{M}{Q_N}\right)^{\eta}$, depends on the South's openness to imports of intermediate goods, M, and on the aggregate Northern technological level, $Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}$) and on $\tilde{Q}^{\sigma}$ (the sector j South/North technology ratio, where $\tilde{Q} = \frac{q^{k_S(j,t)} * J}{q^{k_N(j,t)} * J} = \frac{QS}{QN} = \hat{q}_j$, $0 < \tilde{Q} < 1$ and σ denotes how quickly the cost of imitation raises in the presence of decreases in the technological-knowledge gap). Finally, $\delta \in [0,1]$ measures the degree of IPR enforcement in the South. We introduce the last effect in two ways: firstly, we fix a direct negative relationship between the IPR parameter and the probability of imitation (the higher the parameter δ, the higher the degree of IPR enforcement in the South and the lower the probability of successful imitation); after, we establish a negative but indirect relationship between δ and $I_S(j,t)$ through $\tilde{Q}$ (the smaller the distance to the technological frontier, that is, the higher $\tilde{Q}$, the more these countries will implement IPR laws, the lower the probability of imitation). These relationships between δ and $I_S(j,t)$ can be justified by the following arguments: there is a broad consensus that IPR inhibit imitation and, in general, developed countries have higher levels of IPR protection.

The consumers' problem is standard: the Northern consumer makes consumption and savings decisions in order to maximize the present value lifetime utility:

$$\max_{\{C_N, C_S^*, a\} t \to \infty} \int_0^\infty u(\bar{C}_N) e^{-\rho t} \, dt \tag{4.8}$$

$$u(\bar{C}_N) = \left(\frac{\bar{C}_N^{1-\theta} - 1}{1-\theta} \right) \tag{4.9}$$

$$\bar{C}_N = C_N^{k} {C_S^f}^{1-k} \tag{4.10}$$

$$\dot{a}_N = r_N a_N + w_N - E_N \tag{4.11}$$

$$E_N = P_N C_N + P_S^f C_S^f \, . \tag{4.12}$$

Where $u(\bar{C}_N)$ is the instantaneous utility function with a constant intertemporal elasticity of substitution (CIES), ρ is the discount rate, $\bar{C}_N$ is the Northern composite good, θ defines the inverse intertemporal elasticity of substitution and $\rho > 0$ is the homogeneous subjective discount rate. Equation (4.10) is a Cobb-Douglas aggregator that expresses the Northern composite good, $\bar{C}_N$, in terms of Northern and Southern final goods, C_N and C_S^f, respectively, both consumed in the North. In the same equation, parameter k corresponds to domestic expenditure-share. The return to assets, a_N, in the North is r_N and the wage rate is w_N. One unit of labour is supplied inelastically during every period. The path of the value of assets, $\dot{a}_N$, is represented in equation (4.11) as being the sum of labour and interest rate income minus Northern consumption expenditures, E_N. In turn, the total Northern expenditures, E_N, are described in expression (4.12).

For the South, the problem is symmetric:

$$\max_{\{C_N^*, C_S, a\} t \to \infty} \int_0^\infty u(\bar{C}_S) e^{-\rho t} \, dt \tag{4.13}$$

$$u(\bar{C}_S) = \left(\frac{\bar{C}_S^{1-\theta} - 1}{1-\theta} \right) \tag{4.14}$$

$$\bar{C}_S = {C_N^f}^{1-b} C_S^{b} \tag{4.15}$$

$$\dot{a}_S = r_S a_S + w_S - E_S \tag{4.16}$$

$$E_S = P_S C_S + P_N^f C_N^f \tag{4.17}$$

where $\ell = 1 - k$, that is, we advocate that both economies consume the same amount on the goods produced in the North.

In addition, we consider that the consumption-based price is the minimum expenditure, E_N, when the composite good index, $\bar{C}_N = 1$, for a given set of prices is given by

$$\bar{P}_N = \left(\frac{P_N}{k}\right)^{k} \left(\frac{P_S^f}{1-k}\right)^{1-k}. \tag{4.18}$$

From usual calculations, we obtain two expressions for consumer demands:

$$C_N = k \frac{\bar{P}_N}{P_N} \bar{C}_N \tag{4.19}$$

$$C_S^f = (1-k) \frac{\bar{P}_N}{P_S^f} \bar{C}_N. \tag{4.20}$$

If we consider these expressions in the household utility maximization problem, we arrive at the usual expression for consumption growth (the standard Euler equation):

$$\frac{\dot{\bar{C}}_N}{\bar{C}_N} = \hat{\bar{C}}_N = \frac{1}{\theta}\left(r_N - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right), \tag{4.21}$$

and, for the South, the problem is similar.

Relatively to equilibrium R&D, we consider the usual derivations and compute the equilibrium growth rate of Q_N as:

$$\hat{Q}_N = I_N\left(q^{(1-\alpha)\alpha^{-1}} - 1\right). \tag{4.22}$$

Bearing in mind the characteristics of the steady state and after some mathematical manipulations, we obtain an equation that shows us the steady state probability of innovation:

$$I_N^* = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1 - MC_S) L_N{}^* A_N{}^{\alpha^{-1}} + \left(1 + \tau_{x_S} - MC_S\right) L_S{}^* \left(A_S \frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}\right] - r^*. \tag{4.23}$$

Knowing that, in steady state, the following equality is verified:

$$g^* = \hat{Q}_N^* = \hat{Y}_N^* = \hat{Y}_S^* = \hat{X}_N^* = \hat{X}_S^* = \hat{R}_N^* = \hat{R}_S^* = \hat{\bar{C}}_S{}^* = \hat{\bar{C}}_N{}^* = \frac{1}{\theta}(r^* - \rho). \tag{4.24}$$

Then, considering (4.22), (4.23), (4.24) and after some mathematical computations, the steady state interest rate is obtained:

$$r^* = \frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1 - MC_S) L_N{}^* A_N{}^{\alpha^{-1}} + \left(1 + \tau_{x_S} - MC_S\right) L_S{}^* \left(A_S \frac{MC_S}{1 + \tau_{x_S}} \right)^{\alpha^{-1}} \right] \right\} \left(q^{(1-\alpha)\alpha^{-1}} - 1\right) + \frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}} - 1 + \frac{1}{\theta}}. \quad (4.25)$$

Now, we can easily achieve the steady state growth rate by using the previous expression in the Euler equation (4.21):

$$g^* = \frac{1}{\theta}\left[\left(\frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} \left[(1 - MC_S) L_N{}^* A_N{}^{\alpha^{-1}} + \left(1 + \tau_{x_S} - MC_S\right) L_S{}^* \left(A_S \frac{MC_S}{1 + \tau_{x_S}} \right)^{\alpha^{-1}} \right] \right\} \left(q^{(1-\alpha)\alpha^{-1}} - 1\right) + \frac{1}{\theta}\rho}{q^{(1-\alpha)\alpha^{-1}} - 1 + \frac{1}{\theta}} \right) - \rho \right]. \quad (4.26)$$

Differentiating the previous expression with respect to the IPR parameter (δ), we reach a negative relationship between the steady state growth rate and the IPR protection, *i.e.*, $\frac{\partial g^*}{\partial \delta} < 0$. This result means that by increasing IPR protection, the steady state growth rate decreases. In other words, in steady state, an increase in the IPR enforcement ($\delta \uparrow$) leads to a decrease in the growth rate, which is common to both countries ($g^* \downarrow$).

4.3. Methodology and data

4.3.1. Empirical approach

Departing from expression (4.26), we aim to check the explanatory power of the proposed model and estimate the IPR value associated with the steady state. This expression is composed by several parameters and three variables: L , A and $\tilde{Q}$. Hence, in order to implement an empirical verification, we need data about labour (L), quality of institutions (A) and technological-knowledge gap ($\tilde{Q}^{-1}$).

In this sense and bearing in mind that $r = f(L, A, \tilde{Q})$, we estimate the following equation:

$$g_{it} = c_i + \lambda\left(\tilde{Q}_{it}\right)^{-1} + \gamma A_{it} + \upsilon L_{it} + u_{it}\,, \quad (4.27)$$

where g_{it} denotes the dependent variable, i represents the country, t is the year, c_i represents the constant term of the econometric model, which encompasses the values of the parameters of expression (4.26) (the unknown intercept for each entity - country),

λ, γ and υ are the coefficients for the independent variables and u_{it} represents the error term.

4.3.2. Data

The data for our work was, in general, gathered from the World Bank. Our database corresponds to a panel which includes 34 countries [30] with different levels of development, namely developed (13) and developing countries (21), and two time periods: 1996-2011 and 2002-2011. Similarly to Hudson and Minea (2013), we consider two groups of countries: developed and developing countries. This classification is based on the World Bank list of economies[31] and data for low,[32] lower middle, upper middle, high income OECD and high income non-OECD countries. For simplification, we refer to the lower middle and upper middle income countries as developing countries and both the OECD and non-OECD high income countries as developed countries.

Comparing the above categories with the United Nations (2012) countries' classification[33] we can verify that, in general, low income countries are classified as developing countries (but few are classified as economies in transition). However, the opposite is not true, that is, there are several developing countries, which are not classified as low income countries. Much of them are middle income countries and some of them are high income countries (non-OECD). The OECD high income countries, normally, correspond to the developed countries.

4.3.2.1. Data on the economic growth rate

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[30] *Developing countries:* Lower middle income (Bolivia; Egypt, Arab Rep.; Guatemala; India; Indonesia; Moldova; Paraguay; Ukraine; Zambia), Upper middle income (Bulgaria; Chile; China; Colombia; Costa Rica; Malaysia; Mexico; Peru; Romania; Russian Federation; South Africa; Thailand). *Developed countries:* High income, nonOECD (Hong Kong SAR, China; Malta; Singapore), High income, OECD (Australia; Canada; Estonia; Hungary; Israel; Italy; Japan; Switzerland; United Kingdom; United States).

[31] World Bank, http://www.healthsystemsglobal.org/Portals/0/files/World_bank_list_july2012.pdf accessed in March, 2013.

[32] In our database we do not consider any low income country due to missing data.

[33] http://www.un.org/en/development/desa/policy/wesp/wesp_current/2012country_class.pdf, accessed in January, 2013.

The economic growth rate is represented by g and corresponds to the annual rate at which a country's income increases. Data on growth rate is from World Bank.[34] We use here the annual percentage growth rate of Gross Domestic Product (GDP) at market prices based on constant 2000 U.S. dollars.

4.3.2.2. Data on the technological-knowledge gap

The technological-knowledge gap ($\tilde{Q}^{-1}$) expresses the technological distance to a certain country, which, in our case, is the USA. Data about the technological-knowledge gap is from the World Bank. Specifically, we choose high-technology exports (as a percentage of manufactured exports) as a proxy for the technological-knowledge gap. We transform the data in order to express it as a distance (in logarithm). We expect a negative sign for the coefficient associated with $\tilde{Q}$, since, according to the related literature (*e.g.*, Fagerberg, 1987), the higher the $\tilde{Q}$, the lower the technological-knowledge gap and the lower the economic growth. Moreover, as Zilibotti (2010) stresses, when a country catches up with the technological-knowledge frontier, innovation becomes its main engine for growth.

4.3.2.3. Data on Labour

Labour, denoted by L is used in the estimation of the production of the final good. Data on labour is also from the World Bank. We use total labour participation rate (in percentage of total population ages 15+). The effect of labour on growth is not clear. For example, Mankiw *et al*. (1992) state that most empirical literature, supported by the Solow model, indicate a negative relationship concerning the impact of labour force growth on economic growth. Motley (1997) sustains that a continuing growth in labour force participation may induce a faster growth in the labour supply and, consequently, in potential GDP. However, the author also concludes that labour supply does not only rely on the participation rate, but on other factors such as the average time spent at work, the length of the workweek and the demographic structure of the population. Hence, Motley (1997) stresses that GDP growth should be explained instead by

[34] Data about economic growth rate, technological gap and labour gathered from the World Bank, http://data.worldbank.org/indicator/all/, accessed in May, 2013.

productivity growth. More recently, Zuleta and Alberico (2007) show that the impact of changes in labour supply can depend on economic structure of the economy. The authors sustain that a reduction in labour supply may affect negatively the current output, although the magnitude of the decrease depends on the relative capital endowment of the economy. Furthermore, despite this negative effect on current output, a decrease in the number of workers can affect positively the growth rate of the country. Moreover, beyond the structure of the economy, Zuleta and Alberico (2007) highlight other potential determinants of the effect of changes in labour supply on economic growth such as factor prices, labour income and interest rates.

4.3.2.4. Data on the quality of institutions

The quality of countries' institutions, A, is related with several dimensions such as government services, property rights and tax laws. In order to construct a proxy for the quality of institutions, we use the Worldwide Governance Indicators of the World Bank,[35] which are constituted by six aggregate indicators: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law and control of corruption. We build a composite indicator where these indicators are the different dimensions considered. To do this construction, we follow a methodology similar to the one underlying the construction of the Human Development Index (HDI). Each indicator can change between -2.5, for the worst, and 2.5, for the best performance of institutions. In this context, we use the computation ratio $\frac{estimation-(-2.5)}{2.5-(-2.5)}$ and we calculate the six indexes or dimensions. Then, to achieve the composite indicator (GOV) we compute a simple arithmetic average: $\frac{I^{VA}+I^{PSAV}+I^{GE}+I^{RQ}+I^{RL}+I^{CC}}{6}$. We attribute equal weights to each dimension to avoid bias and we compute the logarithm of GOV.

We anticipate a positive signal for the coefficient of GOV because the related literature sustains a positive relationship between the quality of institutions and economic growth (see, for example, Gradstein, 2003, for a detailed analysis on the impact of the quality of institutions on economic growth). Valeriani *et al.* (2011), for

[35] http://info.worldbank.org/governance/wgi/index.aspx#home, accessed in May, 2013.

instance, conclude that institutional quality has a positive and significant effect on economic growth for all institutional indicators in analysis. They also conclude that this result is different for developed and developing countries, but only in terms of the size of the impact.

4.3.2.5. Data on the control variables

We insert a set of control variables in our econometric model in order to test the robustness of the estimation. We consider variables frequently used in the existing literature such as openness, investment, initial funding available for R&D expenditures, government consumption, education and economic freedom.

Openness

According to several authors, it is useful to insert a measure of openness as a control variable (*e.g.*, Versakelis, 2001; Chen and Puttitanun, 2005; Branstetter *et al*., 2011; Kim *et al*., 2012; Hudson and Minea, 2013). We use the sum of exports and imports of goods and services (share of GDP) as the measure of openness, OPEN, and the data is gathered from the World Bank.[36] In line with the empirical literature on this issue (*e.g.*, Harrison, 1996), we expect a positive sign for this coefficient. However, although at a first glance if a country is open to international market, it can benefit from, for instance, knowledge and technology transfers, this effect is not consensual and it can be related to the countries' development level (*e.g.*, Moskalyk, 2008). For example, Chen and Puttitanun (2005) defend that there can be arguments both for a negative and a positive effect of openness on IPR. Hudson and Minea (2013) find a negative effect of openness on innovation and Yanikkaya (2003), using a large number of openness measures, shows that the effect of trade liberalization on growth is not always clear. Moreover, this author states that trade barriers can be positive for economic growth (namely for developing economies). Nevertheless, among the several measures used in this study, the author considers that the sum of exports and imports as proportion of GDP is the most elementary measure of trade amount (trade openness), and shows that economies will grow faster if they have higher trade shares.

[36] http://data.worldbank.org/indicator/all/, accessed in October, 2013.

Investment

We consider two measures of investment in our empirical study. Firstly, we use the gross capital formation (GCF) (as a percentage of GDP), following Falvey *et al.* (2006), Apergis *et al.* (2007) and Kim *et al.* (2012). GCF is composed by expenses on increments to the fixed assets of the economy (such as machinery and construction of roads, schools, commercial and industrial buildings), net changes in the degree of stocks and net acquisitions of valuables. Both Falvey *et al.* (2006) and Apergis *et al.* (2007) expect a positive sign for the estimated coefficient of this variable and both find a positive and statistically significant effect of investment on economic growth. Park and Ginarte (1997) also obtain a positive sign for the impact of investment on growth. Secondly, we use the electric power consumption (kWh *per capita*) as a proxy for infrastructure, INFRA, as in Hudson and Minea (2013). According to these authors, the presence of good infrastructures may promote innovation and economic growth and, then, a positive estimated coefficient for this variable is expected. The success of manufacturing and agricultural activities is settled by infrastructure. Moreover, investments in water, sanitation, energy, housing and transport improve lives and contribute to decrease poverty. Finally, new information and communication technologies stimulate growth, help the supply of health and other services, enlarge the range of education and reinforce both social and cultural advances (World Bank, 2013).[37] Hudson and Minea (2013) find neither clear results for the sign of this coefficient nor results statistically significant. Data for these two variables is gathered from the World Bank,[38] and the electric power consumption is in logarithm.

Funding available for R&D expenditures

Initial funding available for R&D expenditures is measured by a proxy used, for example, by Kanwar and Evenson (2003): the gross domestic savings (as a percentage of GDP) lagged one period, GDS. Kanwar and Evenson (2003) choose this proxy because they consider that R&D investment is essentially financed by internal funds

[37] http://data.worldbank.org/topic/infrastructure, accessed in January, 2013.
[38] http://data.worldbank.org/indicator/all/, accessed in October, 2013.

(*e.g.*, Hall, 1992; Himmelberg and Petersen, 1994) and conclude that savings have a positive and significant effect on R&D. As R&D is considered to be an important engine for promoting innovation and, in turn, for economic growth, we expect a positive estimated coefficient for this variable. The data is from the World Bank.[39]

Government consumption

Government consumption is the general government final consumption expenditure (percentage of GDP), GOVCONS, and the data is from the World Bank.[40] This variable, which we compute in logarithm, is used by Gould and Gruben (1996) and Apergis *et al.* (2007). Gould and Gruben (1996) find a negative and significant effect of government spending on economic growth, while Apergis *et al.* (2007) conclude that, for OECD countries, the effect is positive and statistically significant but, for non-OECD countries, the effect is negative and significant. According to Apergis *et al.* (2007), the sign for the estimated coefficient associated with this variable is not clear because government consumption can have a positive or a negative result, depending mostly on the nature of expenditures. For instance, if we consider productive expenditures (*e.g.*, on education and infrastructures), we should expect a positive effect, but if we consider non-productive expenditures, these may block economic growth (*e.g.*, Barro and Sala-i-Martin, 2004).

Education

According to the World Bank (2013),[41] education is a crucial instrument to reduce both poverty and inequality and is a fundamental basis for sustained economic growth. Lucas (1988) develops a modelling framework where human capital is the main engine of growth. Several published studies use education as a control variable (*e.g.*, Park and Ginarte, 1997; Apergis *et al.*, 2007; Groizard, 2009; Kim *at al.*, 2012; Hudson and Minea, 2013). Apergis *et al.* (2007) expect and obtain a positive estimated sign concerning the impact of education (secondary schooling) on economic growth. Also, Park and Ginarte (1997) and Hudson and Minea (2013) find a positive effect of

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[39] http://data.worldbank.org/indicator/all/, accessed in October, 2013.
[40] http://data.worldbank.org/indicator/all/, accessed in October, 2013.
[41] http://data.worldbank.org/topic/education, accessed in January, 2013.

education on growth. As a proxy of education, we consider the index of human capital *per capita* based on years of schooling and returns to education, EDUC, in logarithm. Data is from the Penn World Table, version 8.0.[42]

Economic freedom

In line with the Heritage Foundation, economic freedom is defined as the fundamental right that every person has to control its own labour and poverty. Furthermore, individuals are considered to be in an economically free society when they are allowed to work, produce, consume and invest whenever they wish and when the state protects that freedom. In these societies, labour, capital and goods are able to move openly and the state avoids any constraint of liberty. Data on economic freedom index, EF, from The Heritage Foundation,[43] is used in logarithm and as a moving average of two years.

This index covers ten types of freedom but they can be grouped in four main classes: Rule of Law (property rights and freedom for corruption), Limited Government (fiscal freedom and government spending), Regulatory Efficiency (business freedom, labour freedom and monetary freedom) and Open Markets (trade freedom, investment freedom and financial freedom). Each one of these types of freedoms is individually classified on a scale of 0 to 100 and the overall economic freedom score is calculated by the average of the ten individual scores. The use of economic freedom as a control variable is common in the literature: Park and Ginarte (1997) use the market freedom index and Chen and Puttitanun (2005) use the economic freedom index. The former article finds a positive effect of market freedom on the growth rate. The latter expects a positive relation for the impact of economic freedom on IPR and also for the effect of economic freedom on innovation. However, the authors conclude for a positive but insignificant effect for the first relationship and a negative but insignificant effect for the second one in developing countries. Therefore, according to the literature, we expect to get a positive estimation for the coefficient associated to economic freedom.

A systematization of the information on the used variables is proposed in Table 4.1.

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[42] http://www.rug.nl/research/ggdc/data/penn-world-table, accessed in October, 2013.
[43] http://www.heritage.org/index/, accessed in October, 2013.

Table 4.1: Variables and Sources

Variable	Description	Source
Growth rate (g)	GDP annual growth rate	World Bank Indicators http://data.worldbank.org/indicator/all/
Technological gap ($\widetilde{\tilde{Q}^{-1}}$ or l($\tilde{Q}^{-1}$) when it is in logarithm)	High-technology exports	World Bank Indicators http://data.worldbank.org/indicator/all/
Labour (L)	Total labour participation rate	World Bank Indicators http://data.worldbank.org/indicator/all/
Governance (GOV or lGOV when it is in logarithm)	Governance index	Worldwide Governance Indicators – World Bank http://info.worldbank.org/governance/wgi/index.aspx#home
Openness (OPEN)	The sum of exports and imports of goods and services (% GDP)	World Bank Indicators http://data.worldbank.org/indicator/all/
Investment 1 (GCF)	Gross capital formation (% GDP)	World Bank Indicators http://data.worldbank.org/indicator/all/
Investment 2 (INFRA or lINFRA when it is in logarithm)	Infrastructure (electric power consumption *per capita*)	World Bank Indicators http://data.worldbank.org/indicator/all/
Funding available for R&D expenditures (GDS)	Gross domestic savings (% GDP)	World Bank Indicators http://data.worldbank.org/indicator/all/
Government consumption (GOVCONS)	Government final consumption expenditure	World Bank Indicators http://data.worldbank.org/indicator/all/
Education (EDUC or lEDUC when it is in logarithm)	Index of human capital *per capita* (years of schooling and returns to education)	Penn World Table, version 8.0 http://www.rug.nl/research/ggdc/data/penn-world-table
Economic freedom (EF or lEF when it is in logarithm)	Economic freedom index	The Heritage Foundation, 2013 Index of Economic Freedom http://www.heritage.org/index/

4.4. Estimation results

4.4.1. First stage

We propose, using data for two samples, a large one from 1997 to 2011 and a smaller one from 2002 to 2011 (both with 34 countries),[44] a panel data econometric model of the type:

$$g_{it} = c_i + \lambda\left(\tilde{Q}_{it}\right)^{-1} + \gamma A_{it} + \upsilon L_{it} + bX_{it} + u_{it}\,, \tag{4.28}$$

where X_{it} represents the set of control variables and the other variables correspond to the main explanatory variables as identified in equation (4.27).

For our estimation, we have run both random effects (RE) and fixed effects (FE). The Hausman test allows us to conclude in favour of the fixed effects model (FEM) for all specifications. Since some of the proposed variables are significantly correlated (for example, governance and economic freedom; governance and infrastructure; education

[44] For the large sample, we use linear extrapolation in order to compute some values since, before 2002, data is available only in a two-year basis.

and infrastructure), we test different specifications of our model. For all of them, test results sustain the choice for both cross-section and period fixed-effects estimation as shown in Tables 4.2 and 4.3: both χ^2 and F tests clearly allow rejecting the null hypothesis that the cross-section and period effects are redundant.

Tables 4.2 and 4.3 offer a systematization of the FEM estimation results for distinct specifications: for the samples 1997-2011 and 2002 -2011, respectively.

Table 4.2: Estimation results for alternative specifications (1997-2011)

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	Developed 1997-2011	Developing 1997-2011
L	-0.198** (0.039)	-0.202** (0.040)	-0.159* (0.062)	-0.162* (0.059)	-0.204** (0.041)	-0.189** (0.049)	-0.185* (0.057)	-0.188** (0.018)	-0.570*** (0.008)	-0.147* (0.095)
lGOV	9.501*** (0.003)	9.821*** (0.003)	8.653** (0.034)	8.990** (0.034)				8.788* (0.073)	13.138 (0.250)	11.788** (0.031)
$l(\tilde{Q}^{-1})$	0.193 (0.687)	0.198 (0.689)	-0.258 (0.652)	-0.254 (0.664)	0.329 (0.478)	0.488 (0.307)	0.515 (0.280)	-0.222 (0.649)	1.023 (0.574)	-0.491 (0.273)
OPEN	0.047*** (0.003)	0.047*** (0.003)	0.045*** (0.009)	0.045*** (0.008)	0.046*** (0.001)	0.051*** (0.000)	0.052*** (0.000)	0.049*** (0.002)	0.034** (0.049)	0 .099** (0.030)
GCF	0.335*** (0.000)	0.326*** (0.000)	0.297*** (0.000)	0.288*** (0.000)	0.340*** (0.000)	0.342*** (0.000)	0.346*** (0.000)	0.271*** (0.000)	0.276 (0.180)	0 .193** (0.028)
GDS	-0.142** (0.046)	-0.146** (0.045)	-0.096 (0.228)	-0.010 (0.221)	-0.146* (0.054)	-0.141* (0.064)	-0.138* (0.059)			
GOVCONS	-0.417*** (0.008)	-0.417*** (0.009)	-0.316* (0.061)	-0.316* (0.066)	-0.422*** (0.010)	-0.398** (0.014)	-0.393** (0.014)	-0.263* (0.090)	-0.723** (0.012)	-0.107 (0.528)
lEDUC	13.471** (0.015)	9.823** (0.049)	13.395 (0.170)	9.551 (0.256)	9.315 (0.108)					
lEF	-16.566*** (0.000)	-16.583*** (0.000)			-16.280*** (0.000)	-16.248*** (0.000)	-16.239*** (0.000)			
lINFRA	-1.193 (0.496)		-1.258 (0.544)			0.492 (0.758)				
Constant	84.299*** (0.001)	79.263*** (0.000)	11.007 (0.400)	5.623 (0.495)	72.616*** (0.000)	76.061*** (0.001)	79.313*** (0.000)	13.551*** (0.009)	43.500*** (0.004)	11.482* (0.060)
Summary of statistics										
R-squared	0.25507718	0.25403691	0.1988328	0.19767748	0.24186105	0.23650986	0.23618131	0.18447653	0 .28203571	0 .18388346
Adjusted R-squared	0.24014887	0.24060958	0.18441179	0.18486594	0.22975504	0.2243184	0.22553046	0.17474861	0.25912196	0 .16798509
F-stat (p-value)	8.44 (0.0000)	9.09 (0.0000)	8.41 (0.0000)	9.02 (0.0000)	8.74 (0.0000)	8.69 (0.0000)	9.35 (0.0000)	11.42 (0.0000)	23.90 (0.0000)	12.29 (0.0000)
Hausman test: χ^2(p-value)	89.72 (0.0000)	88.67 (0.0000)	62.00 (0.0000)	61.54 (0.0000)	80.08 (0.0000)	79.37 (0.0000)	72.32 (0.0000)	50.39 (0.0000)	58.46 (0.0000)	34.87 (0.0000)

Notes: (1) significance level at 1% (***), 5% (**) and 10% (*); *p-values* in parenthesis. (2)To avoid problems such as heteroskedasticity and serial correlation, we estimate the robust standard errors.

Table 4.3: Estimation results for alternative specifications (2002-2011)

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VI.I)	(VII)	(VII.I)	(VIII)	(VIII.I)	Developed 2002-2011	Developing 2002-2011
L	0.110 (0.529)	0.075 (0.662)	0.063 (0.702)	0.026 (0.875)	0.066 (0.680)	0.105 (0.521)	0.058 (0.713)	0.048 (0.774)	0.009 (0.954)	-0.029 (0.861)	0.023 (0.893)	-0.833* (0.056)	-0.025 (0.848)
lGOV	11.367** (0.012)	11.905** (0.015)	11.265** (0.017)	11.830** (0.021)						12.109** (0.027)	11.067* (0.060)	30.394* (0.056)	15.428*** (0.007)
l $(\tilde{Q}^{-1})$	-0.076 (0.928)	0.046 (0.958)	-0.647 (0.521)	-0.524 (0.617)	0.237 (0.787)	0.184 (0.816)	-0.338 (0.722)	0.029 (0.972)	-0.991 (0.206)	-0.958 (0.312)	-1.188 (0.123)	2.098 (0.457)	-1.589* (0.071)
OPEN	0.036* (0.086)	0.040* (0.075)	0.041* (0.085)	0.0451* (0.074)	0.038* (0.074)	0.035* (0.090)	0.041* (0.082)	0.035* (0.095)	0.046** (0.048)	0.040* (0.099)	0.049** (0.045)	-0.010 (0.670)	0 .138*** (0.004)
GCF	0.341*** (0.001)	0.312*** (0.003)	0.294*** (0.004)	0.263*** (0.009)	0.347*** (0.001)	0.376*** (0.000)	0.327*** (0.001)	0.336*** (0.001)	0.288*** (0.003)	0.231*** (0.006)	0.258** (0.011)	0 .222 (0.335)	0 .060 (0.391)
GDS	-0.126 (0.192)	-0.143 (0.147)	-0.080 (0.430)	-0.097 (0.353)	-0.153 (0.142)	-0.136 (0.190)	-0.091 (0.406)	-0.155 (0.135)					
GOVCONS	-0.424** (0.036)	-0.399** (0.050)	-0.376 (0.113)	-0.350 (0.145)	-0.379* (0.059)	-0.396** (0.044)	-0.342 (0.143)	-0.400* (0.056)		-0.341 (0.155)		-1.308** (0.017)	-0.054 (0.785)
lEDUC	2.870 (0.813)	-10.733 (0.388)	6.143 (0.657)	-8.156 (0.542)	-9.509 (0.497)								
lEF	-18.931*** (0.002)	-19.103*** (0.002)			-19.059*** (0.003)	-19.001*** (0.002)		-18.747*** (0.005)					
lINFRA	-4.155 (0.103)		-4.375 (0.104)			-3.864 (0.124)	-3.661 (0.155)						
Constant	111.125*** (0.002)	95.317*** (0.003)	31.826* (0.095)	14.409 (0.341)	86.735*** (0.005)	104.735*** (0.002)	25.033 (0.222)	77.692*** (0.006)	-8.630 (0.321)	8.263 (0.366)	-2.491 (0.787)	82.054** (0.045)	5.006 (0.478)
Summary of statistics													
R-squared	0.23321417	0.22519473	0.18676501	0.1778699	0.20756617	0.2166936	0 .16969818	0 .20470566	0.13210738	0 .16822058	0.14754664	0 .33938349	0 .2083324
Adjusted R-squared	0.2099076	0.20406368	0.16458587	0.15799968	0.18841369	0.19776173	0 .15219181	0 .18793741	0.12174448	0 .15323356	0.13478536	0 .30715829	0 .18493335
F-stat (p-value)	6.23 (0.0000)	5.94 (0.0001)	6.38 (0.0000)	6.68 (0.0000)	5.07 (0.0004)	5.95 (0.0001)	3.89 (0.0034)	5.32 (0.0004)	6.06 (0.0009)	6.17 (0.0002)	6.69 (0.0002)	114.21 (0.0000)	7.13 (0.0004)
Hausman test: χ^2***(p-value)***	40.42 (0.0000)	36.58 (0.0000)	33.13 (0.0001)	30.41 (0.0002)	30.20 (0.0002)	36.36 (0.0000)	24.89 (0.0008)	28.59 (0.0002)	8.83 (0.0655)	24.79 (0.0004)	19.10 (0.0018)	45.20 (0.0000)	28.42 (0.0001)

Notes: (1) significance level at 1% (***), 5% (**) and 10% (*); *p-values* in parenthesis. (2)To avoid problems such as heteroskedasticity and serial correlation, we estimate the robust standard errors.

For the specifications I, with all control variables, we obtain interesting results: for the period between 1997 and 2011, all variables are statistically significant except technological-knowledge gap and infrastructure; for the period from2002 to 2011, labour, initial funds available for R&D expenditures and education have statistically insignificant estimated coefficients. Moreover, initial funds available for R&D expenditures, economic freedom and infrastructure appear with estimated signs not in line with the literature for both samples. For the larger sample, technological-knowledge gap also does not have the expected sign.

There is strong correlation between some variables (see Tables 4.B.1.1 and 4.B.2.2 in the Appendix B.2.). For the large sample, we verify that the variables economic freedom and infrastructure are strongly correlated with governance; the same situation occurs between education and infrastructure. In the other sample, beyond these two correlations, there is also a strong correlation between economic freedom and infrastructure. In this sense, it is necessary to define further specifications.

For the larger sample (Table 4.2) we define different specifications, for different sets of variables.

As specification II shows, in the absence of the variable infrastructure, only the estimated coefficient of technological-knowledge gap is not statistically significant. Moreover, this last variable is statistically significant only in the specification for developing countries in the period between 2002 and 2011. Concerning the expected sign of the variables, the results show that several variables have estimated signs different from which we would expect from the literature: technological-knowledge gap, initial funds available for R&D expenditures and economic freedom.

If we exclude economic freedom (specification III), the results are worse because initial funds available for R&D expenditures, education and infrastructure become statistically insignificant.

We continue to test the model by estimating different specifications (eliminating some variables and adding others, especially in order to eliminate the presence of correlation between control variables) and we get better and worse results. For instance, while if we drop governance and infrastructure (specification V), only the variables technological gap and education remain not statistically significant, although the sign estimated for economic freedom is negative, in specification VI, with no governance and no education, both technological-knowledge gap and education are statistically not significant, and initial funds available for R&D expenditures and economic freedom have signs different from the expected.

To maintain governance (one of our main variables), we test the model without economic freedom, infrastructure, initial funds available for R&D expenditures and education (specification VIII). In this specification, technological-knowledge gap is the only statistically insignificant variable and all variables reveal the expected sign.

In a similar way, for the period from2002 to 2011 (Table 4.3), we proposed distict specifications in order to solve the problems of correlations between the explanatory variables. We start by estimating the model without infrastructure (specification II). In this case, technological-knowledge gap, initial funds available for R&D expenditures, labour and education are not statically significant and economic freedom has an estimated sign in opposition with expected.

Alternatively, if, for instance, we estimate the model without governance and education (specification VI), labour, technological-knowledge gap, initial funds available for R&D and infrastructure are statistically insignificant and the estimations associated with the variables openness and gross capital formation are as expected. However, as compared with the result obtained for the larger sample, for the smaller sample this estimation does not remove the correlation between the variables, such as we stated above. Hence, we estimate the model without governance, education and economic freedom (specification VI.I). Results show that only openness and gross capital formation are statistically significant.

Moreover, implementing an estimation by excluding infrastructure, economic freedom, initial funds available for R&D and education (specification VIII), we obtain the expected sign for all variables although labour and technological-knowledge gap are not statistically significant. Instead, by estimating the model without infrastructure, economic freedom, initial funds available for R&D, governance consumption and education (specification VIII.I), we also get the expected sign for all variables (labour changes to a positive sign which is suitable, too) but both labour and technological-knowledge gap remain statistically insignificant.

We can also verify that infrastructure is never statistically significant, technological-knowledge gap is significant only in the specification for developing countries in the period 2002-2011 and for the smaller sample, labour is only statistically significant for the sample of developed countries, initial funds available for R&D expenditures and education are never statistically significant.

According to the related literature, and relatively to the variable infrastructure, Hudson and Minea (2013) also do not find a statistically significant result and they argument this is rather common in the literature, also in line with Schneider (2005). However, while they find a positive estimated effect of infrastructure on innovation, we only find for one of the specifications a positive influence on growth. In respect to the variable education, Chen and Puttitanun (2005) conclude that it has a positive impact on IPR but it is insignificant as in Park and Ginarte (1997) and Maskus (2000). In general, we also obtain a positive (despite being statistically insignificant for some specifications) estimated effect of education on growth. Regarding the variable economic freedom, the same authors state that it does not have a perceptible effect on innovation because the estimated sign is always negative and insignificant. However, in our specifications we obtain a significant negative effect of economic freedom on growth, which is at odds with the literature.

On the other hand, we obtain better results for some other variables. For example, governance, openness and gross capital formation emerge, in general, with positive and significant sign associated. In addition, government consumption has a negative and statistically significant estimation in all specifications except for developing countries, for the period between 1997 and 2011.

Summing up, based on the all the above results, we construct the specifications Mb, the ‘better specifications’, presented in Table 4.4 and which corresponds to the specification VIII in the Tables 4.2 and 4.3. All variables have the expected sign, despite the technological-knowledge gap continues to be statistically insignificant in both samples. Labour and governance consumption are also statistically insignificant for the smaller sample. We can conclude that, as a whole, the results are better for the wide sample.

Table 4.4: Better specifications

	Mb 1997-2011	**Mb 2002-2011**
L	-0.188** (0.018)	-0.029 (0.861)
lGOV	8.788* (0.073)	12.109** (0.027)
l$\tilde{Q}$	-0.222	-0.958 (0.312)
OPEN	0.049*** (0.002)	0.040* (0.099)
GCF	0.2705*** (0.000)	0.231*** (0.006)
GOVCONS	-0.263* (0.090)	-0.341 (0.155)
Constant	13.551*** (0.009)	8.2634133 (0.366)
Summary Statistics		
R-squared	0.18447653	0 .16822058
Adjusted R-squared	0.17474861	0 .15323356
F-stat (p-value)	11.42 (0.0000)	6.17 (0.0002)
Hausman test: χ^2(p-value)	50.39 (0.0000)	24.79 (0.0004)

Notes: (1) significance level at 1% (***), 5% (**) and 10% (*); *p-values* in parenthesis. (2)To avoid problems such as heteroskedasticity and serial correlation, we estimate the robust standard errors.

Using the 'better specifications',[45] we estimate the regression, in both periods, distinguishing developed and developing countries, in order to study whether there are significant differences.

As it is possible to state from the Tables 4.2 and 4.3, when we estimate the sample of developed countries, only three variables emerge with statistically significant estimated coefficients: labour, openness and government consumption in the case of the period 1997-2011, and labour, governance and government consumption for the smallest sample. For the former, we gather the expected sign for governance, openness and gross capital formation. Labour and government consumption have negative estimated signs which, as stated above, is in line with some strands in the literature. The estimated coefficient of the technological-knowledge gap presents a positive sign, in line with what might be expected from convergence theories: when a country is near of the technological frontier, its technological-knowledge gap is lower but its economic growth rate will be also lower (*e.g.*, Fagerberg, 1987; Barro and Sala-i-Martin, 2004,

[45] Note that when we obtain the correlation matrix for the developed countries' samples (see Tables 4.B.2.3. and 4.B.2.4. in the Appendix B.2.), some correlations appear, namely: for the period between 1997 and 2011, labour is correlated with governance and governance is correlated with government consumption; for the period between 2002 and 2011, labour is correlated with governance, governance and openness are correlated with government consumption.

chap. 8). Relatively to the latter sample, only the estimated sign of the openness coefficient changes to a negative sign (which is not unusual in the literature).

When we consider only the developing countries, we obtain the expected sign for all coefficients, labour, governance, openness and gross capital formation, which are statistically significant in the larger sample while governance, technological-knowledge gap and openness are significant in the smaller sample. Note that, only in this last specification the variable technological-knowledge gap emerges as statistically significant.

4.4.2. Second stage

In this section, we obtain the estimated value of the IPR parameter, δ. We achieve this value residually, that is, from the values of the coefficients estimated in Section 4.4.1. and the descriptive statistics (Tables in Appendix B.1.), namely, the average. We use this alternative procedure in two stages rather than using a certain measure of IPR and finding, through an econometric causality approach, the IPR effect on the growth rate. By using this procedure, we overcome some limitations associated with the divergence of IPR measures used in related empirical literature that can induce some bias in the analysis (*e.g.*, Chu, 2009b).

Firstly, by using the coefficients found with the "better specifications" (ignoring the residual term due to the absence of data) and the averages of the variables, we obtain a growth rate of about 3.67 for the period from1997 to 2011 and around 4.01 for the period between 2002 and 2011. Then, by considering these values and those presented in Connolly and Valderrama (2005) and Afonso (2012)[46] – Table 4.B.3.1 in the Appendixex B.3. – into the expression (4.26), we obtain the following results: with a growth rate of 3.67, the value of the IPR parameter is about 0.41 and with a growth rate of 4.01, δ is aproximately 0.39. Therefore, these results seem to sustain that economic growth rate is higher for a lower IPR degree.

Furthermore, we implement the same procedure for the groups of developed and developing countries. For the period between 1997 and 2011, we obtain a growth rate

[46] We use values of Afonso (2012) for variables/parameters for which Connolly and Valderrama (2005) do not present values: MC_S and $\tilde{Q}$.

about 2.85 and an IPR parameter about 0.49 for developed countries, and an economic growth rate about 4.19 and a δ about 0.38 for developing countries. For the smaller period, we find a growth rate about 2.56 and an IPR value about 0.52 for developed countries and a growth rate about 4.91 and an IPR parameter about 0.33 for developing countries. Therefore, we can conclude that developed countries have a higher degree of IPR protection but a lower growth rate. This result is according to the literature which defends that developed countries generally have higher levels of IPR protection (*e.g.*, Lai and Qiu, 2003; Grossman and Lai, 2004; Naghavi, 2007; Dinopoulos and Segerstrom, 2010). Moreover, developed countries have smaller estimated growth rates because these countries are near the technological-knowledge frontier and, in line with convergence theories, poor economies grow faster than richer ones (*e.g.*, Fagerberg, 1987; Barro and Sala-i-Martin, 2004, chap. 8).

4.5. Concluding remarks

This chapter has conveyed an empirical analysis to verify the effect of IPR on economic growth. Since the IPR effect on growth is not unambiguous and a great part of the existing literature does not study this effect directly, we evaluate empirically the theoretical results achieved in Azevedo *et al*. (forthcoming) by using a panel dataset of 34 developed and developing countries, over the 1997-2011 and 2002-2011 periods. Moreover, given that there is an IPR measure commonly used among the existing studies, but which can constitute a bias in the investigation, we use an alternative procedure: we estimate the IPR value residually.

In order to do this study, we divide the analysis in two stages: firstly, we estimate a model to test the main determinants of economic growth within the specific theoretical model proposed in Azevedo *et al*. (forthcoming); secondly, and by using the results obtained in the first stage, we obtain the estimated value of the growth rate and, since we have the values for all parameters and variables of our model except for the IPR parameter, we compute this parameter in residual terms.

In the first stage of this procedure, we obtain some interesting results. We can conclude that, while some variables did not present an estimated coefficient with the expected sign and/or they were not statistically significant, others are in line with the literature. For instance, labour, which is acceptable in the literature as potentially impinging positively or negatively on growth, for the period from 1997 to 2011 has always statistically significant, with a positive estimated sign; for the period between 2002 and 2011 the estimated impact was, in general, negative, despite being statistically insignificant. The technological-knowledge gap variable only observes an estimated significant coefficient for the sample composed by developing countries in the period 2002-2011. According to the existing literature, it is possible to obtain a positive or a negative impact of openness on growth and we find that, except for developed countries in the period between 2002 and 2011, openness has a positive and significant estimated effect on growth. Moreover, our results point to a negative estimated impact, although insignificant in some specifications, of government consumption on growth. Relatively to education, our results are not very good because it was expected a positive sign for this coefficient and, for some specifications, it reveals a negative one, and appears frequently has not statistically significant. The variable infrastructure has not a clear expected sign and we also find both positive and negative estimated coefficients (in spite of prevailing the negative ones). In what regards economic freedom, although we do not obtain the expected sign, the estimated coefficient is statistically significant in our specifications. The same does not occur for initial funding available for R&D expenditures.

This analysis allowed us to choose some specifications which we then used in the second stage of our procedure. On the basis of the results obtained from the diverse specifications (and taking into account the correlations between the control variables), we have chosen the control variables to use in the final specifications and we have arrived to what we denominated as 'better specifications'. In these specifications, we have used the three main variables (labour, technological-knowledge gap and governance) plus three control variables (openness, government consumption and gross capital formation). Note that governance has not only estimated coefficients with the expected positive sign but also emerges as statistically significant and gross capital formation is, in general, associated with positive – according to expected – and significant estimated coefficients.

In the second stage, and by using the results from the first one and some additional calculations, we found the value of IPR for different samples, and computed estimated different growth rates, which allowed us to conclude in favour of a negative effect of IPR protection on growth.

In sum, this work confirms the theoretical model which constitutes the basis of this work and presents an alternative approach to the most common approaches for analysing the effect of IPR on growth. Our finding suggests that by increasing the level of IPR protection, the growth rate may decrease. Moreover, we find that developed countries, with higher levels of IPR protection, also have a lower growth rate.

Further research on this issue is necessary. Other IPR measures and other models should be used in order to investigate the IPR effect on growth. This study is just another contribution to try to understand this effect and finds the opposite sign to that found by the majority of the empirical literature. Then, much more work must be done so that we can conclude the true sign of the effect in analysis. We separate countries into two samples according with their stage of development (developed or developing countries) and it can be useful to make a more detailed study in order to allow us to verify whether the IPR effect on growth relies on the countries' level of development. Another interesting point for future research is to analyse the inverse effect, that is, to understand the effect of economic growth on IPR level.

Appendix B

B.1. Descriptive statistics

Table 4.B.1.1: Descriptive statistics (1997-2011)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	510	3.673742	3.786218	-14.8	14.76322
$\tilde{Q}$	510	0.616604	0.5564539	0.0041965	2.610868
L	510	61.68059	8.089055	41	80.2
GOV	510	0.5681598	0.1664209	0.2934967	0.8657532
OPEN	510	96.3597	80.36573	18.75639	460.4711
EDUC	510	2.728484	0.4433331	1.701512	3.618748
EF	510	65.03392	10.63625	40.6	90.5
GDS	510	22.70171	10.9816	-15.7957	53.1975
INFRA	510	4212.767	3806.334	250.6307	17319.23
GCF	510	22.66436	5.949575	10.21567	48.31465
GOVCONS	510	15.06725	4.762215	4.997301	28.58926
lGOV	510	-0.6092874	0.2987948	-1.225889	-0.1441554
l$\tilde{Q}$	510	-0.9551553	1.113195	-5.473502	0.9596828
lEF	510	4.161723	0.1624186	3.703768	4.50535
lEDUC	510	0.9894346	0.1733228	0.531517	1.286128
lINFRA	510	7.892178	1.033089	5.523981	9.759573

Table 4.B.1.2: Descriptive statistics (2002-2011)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	340	4.01172	3.745092	-14.8	14.76322
$\tilde{Q}$	340	0.6393346	0.5744231	0.0069841	2.610868
L	340	61.65	8.169583	41	80.1
GOV	340	0.5677581	0.1661159	0.3012039	0.8596657
OPEN	340	100.0407	85.00567	21.16393	460.4711
EDUC	340	2.770244	0.4345213	1.707196	3.618748
EF	340	65.43515	10.58809	47.6	89.9
GDS	340	23.00692	11.30302	-15.7957	53.1975
INFRA	340	4359.588	3819.988	376.687	17319.23
GCF	340	22.91686	6.193413	11.0217	48.31465
GOVCONS	340	15.27431	4.655923	6.313539	28.58926
lGOV	340	-0.6097436	0.2978306	-1.199968	-0.1512117
l$\tilde{Q}$	340	-0.8953886	1.059876	-4.964116	0.9596828
lEF	340	4.168387	0.1584782	3.862833	4.498698
lEDUC	340	1.005578	0.1676385	0.5348523	1.286128
lINFRA	340	7.952117	1.002226	5.931415	9.759573

Table 4.B.1.3: Descriptive Statistics (1997-2011, developed countries)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	195	2.847615	3.381145	-14.07228	14.76322
$\tilde{Q}$	195	0.8634897	0.5414338	0.2083888	2.610868
L	195	59.70051	6.548318	47.2	68.3
GOV	195	0.7455198	0.0735799	0.5889007	0.8657532
OPEN	195	125.4406	114.323	18.75639	460.4711
EDUC	195	3.060762	0.2773383	2.470783	3.618748
EF	195	73.87513	9.130828	55.8	90.5
GDS	195	24.26939	8.86375	11.29243	53.1975
INFRA	195	7837.536	3606.923	3188.382	17319.23
GCF	195	22.20062	4.671904	12.16775	38.69689
GOVCONS	195	17.63167	4.736474	8.043869	28.58926
lGOV	195	-0.2987091	0.1016224	-0.5294977	-0.1441554
l$\tilde{Q}$	195	-0.3216852	0.5901649	-1.568349	0.9596828
lEF	195	4.294669	0.1250057	4.021774	4.50535
lEDUC	195	1.114554	0.0910726	0.9045349	1.286128
lINFRA	195	8.875444	0.4173701	8.067268	9.759573

Table 4.B.1.4: Descriptive Statistics (2002-2011, developed countries)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	130	2.558483	3.529498	-14.07228	14.76322
$\tilde{Q}$	130	0.8875917	0.5648435	0.2083888	2.610868
L	130	59.83923	6.463655	48.3	68.3
GOV	130	0.7446407	0.0737624	0.5889007	0.8596657
OPEN	130	131.0608	122.8263	21.16393	460.4711
EDUC	130	3.095711	0.2696302	2.600136	3.618748
EF	130	74.93038	8.642805	60.6	89.9
GDS	130	24.12942	8.945888	11.29243	53.1975
INFRA	130	8019.341	3558.345	3545.171	17319.23
GCF	130	21.45144	4.606044	12.16775	38.69689
GOVCONS	130	17.85326	4.710555	8.418385	28.58926
lGOV	130	-0.2999494	0.1025477	-0.5294977	-0.1512117
l$\tilde{Q}$	130	-0.3013061	0.6053532	-1.568349	0.9596828
lEF	130	4.309898	0.1161837	4.104295	4.498698
lEDUC	130	1.126235	0.0874531	0.9555637	1.286128
lINFRA	130	8.904984	0.4021486	8.173342	9.759573

Table 4.B.1.5: Descriptive Statistics (1997-2011, developing countries)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	315	4.185154	3.935563	-14.8	14.24365
$\tilde{Q}$	315	0.46377	0.5094409	0.0041965	2.398365
L	315	62.90635	8.696706	41	80.2
GOV	315	0.4583655	0.099611	0.2934967	0.7498185
OPEN	315	78.35721	39.29807	22.22955	220.4068
EDUC	315	2.522789	0.4000866	1.701512	3.244556
EF	315	59.56079	7.29944	40.6	78.45
GDS	315	21.73125	12.01981	-15.7957	52.65314
INFRA	315	1968.863	1495.652	250.6307	6485.8
GCF	315	22.95144	6.608965	10.21567	48.31465
GOVCONS	315	13.47975	4.036063	4.997301	27.39892
lGOV	315	-0.8015501	0.2033616	-1.225889	-0.2879241
l$\tilde{Q}$	315	-1.347303	1.179028	-5.473502	0.8747873
lEF	315	4.079422	0.1238399	3.703768	4.362462
lEDUC	315	0.9119799	0.1668291	0.531517	1.176978
lINFRA	315	7.283489	0.8064458	5.523981	8.77737

Table 4.B.1.6: Descriptive Statistics (2002-2011, developing countries)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
g	210	4.911343	3.596392	-14.8	14.24365
$\tilde{Q}$	210	0.4856516	0.5255567	0.0069841	2.398365
L	210	62.77095	8.897603	41	80.1
GOV	210	0.4582593	0.0994577	0.3012039	0.7498185
OPEN	210	80.83781	37.94599	29.065	210.3743
EDUC	210	2.568765	0.3933194	1.707196	3.244556
EF	210	59.55714	6.703573	47.6	78.45
GDS	210	22.31203	12.51241	-15.7957	52.65314
INFRA	210	2094.027	1537.949	376.687	6485.8
GCF	210	23.82402	6.852752	11.0217	48.31465
GOVCONS	210	13.67783	3.84286	6.313539	23.76387
lGOV	210	-0.801521	0.2018318	-1.199968	-0.2879241
l$\tilde{Q}$	210	-1.263154	1.113756	-4.964116	0.8747873
lEF	210	4.080785	0.1106295	3.862833	4.362462
lEDUC	210	0.9308865	0.1618687	0.5348523	1.176978
lINFRA	210	7.362247	0.7842514	5.931415	8.77737

B.2. Correlation matrixes

Table 4.B.2.1: Correlation matrix (1997-2011)

	L	lGOV	l$\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	-0.2211	1.0000								
$\tilde{Q}$	0.0982	0.4946	1.0000							
OPEN	-0.0721	0.3076	0.3475	1.0000						
GCF	0.1259	-0.0193	0.1428	0.1089	1.0000					
GDS	0.3293	0.1664	0.4321	0.3870	0.4258	1.0000				
lEF	0.1126	0.7566	0.4248	0.3926	-0.0703	0.1984	1.0000			
GOVCONS	-0.3829	0.2721	0.1398	-0.1659	-0.1271	-0.2600	-0.0387	1.0000		
lEDUC	-0.2408	0.5708	0.3373	0.1287	-0.0548	0.0368	0.3362	0.5288	1.0000	
lINFRA	-0.2926	0.7777	0.4106	0.2434	-0.0097	0.1871	0.5180	0.4714	0.8144	1.0000

Table 4.B.2.2: Correlation matrix (2002-2011)

	L	lGOV	l$\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	-0.2109	1.0000								
$\tilde{Q}$	0.0954	0.5027	1.0000							
OPEN	-0.0246	0.3314	0.3706	1.0000						
GCF	0.1179	-0.1296	0.0587	-0.0131	1.0000					
GDS	0.4015	0.1345	0.4180	0.4367	0.3462	1.0000				
lEF	0.0555	0.8324	0.4132	0.4335	-0.1998	0.1387	1.0000			
GOVCONS	-0.3769	0.2899	0.1167	-0.2126	-0.1584	-0.3238	0.0382	1.0000		
lEDUC	-0.2481	0.5764	0.3398	0.1195	-0.1380	0.0159	0.4204	0.5209	1.0000	
lINFRA	-0.2840	0.7848	0.4292	0.2461	-0.0802	0.1517	0.6073	0.4695	0.8058	1.0000

Table 4.B.2.3: Correlation matrix (1997-2011, developed countries)

	L	lGOV	$l\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	0.7684	1.0000								
$\tilde{Q}$	0.1100	0.2908	1.0000							
OPEN	0.0309	0.1380	0.3683	1.0000						
GCF	0.1498	0.0484	-0.2615	0.2395	1.0000					
GDS	0.3678	0.3080	0.1786	0.7034	0.4903	1.0000				
lEF	0.7815	0.6531	0.1730	0.4536	0.2087	0.5348	1.0000			
GOVCONS	-0.5397	-0.6065	-0.2177	-0.5546	-0.2952	-0.6655	-0.7248	1.0000		
lEDUC	0.1592	-0.0679	-0.2222	-0.4687	0.0443	-0.4042	-0.0896	0.3444	1.0000	
lINFRA	0.7600	0.5336	-0.0763	-0.2836	-0.0831	0.0632	0.4262	-0.1999	0.4384	1.0000

Table 4.B.2.4: Correlation matrix (2002-2011, developed countries)

	L	lGOV	$l\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	0.7704	1.0000								
$\tilde{Q}$	0.0854	0.3034	1.0000							
OPEN	0.0378	0.1788	0.3317	1.0000						
GCF	0.1639	0.0903	-0.4208	0.1227	1.0000					
GDS	0.3827	0.3405	0.1581	0.7302	0.4119	1.0000				
lEF	0.7845	0.7224	0.1467	0.4930	0.2033	0.5396	1.0000			
GOVCONS	-0.5273	-0.6118	-0.1936	-0.6146	-0.2452	-0.6944	-0.7495	1.0000		
lEDUC	0.1538	-0.0589	-0.2237	-0.4773	0.2046	-0.3921	-0.0958	0.3176	1.0000	
lINFRA	0.7717	0.5076	-0.0862	-0.2809	0.0279	0.0652	0.4220	-0.1989	0.4468	1.0000

Table 4.B.2.5: Correlation matrix (1997-2011, developing countries)

	L	lGOV	$l\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	-0.3188	1.0000								
$\tilde{Q}$	0.2371	0.2423	1.0000							
OPEN	-0.0949	0.2380	0.3566	1.0000						
GCF	0.1056	0.0558	0.2918	0.0730	1.0000					
GDS	0.3572	0.0917	0.4930	0.1428	0.4190	1.0000				
lEF	0.1014	0.5113	0.2187	0.0852	-0.1508	-0.0014	1.0000			
GOVCONS	-0.2411	0.0089	-0.0118	0.0483	-0.0228	-0.1819	-0.2525	1.0000		
lEDUC	-0.2460	0.2722	0.1687	0.3449	-0.0407	0.0588	-0.0363	0.4353	1.0000	
lINFRA	-0.4690	0.4154	0.1586	0.3902	0.0866	0.1802	-0.0429	0.4512	0.7610	1.0000

Table 4.B.2.6: Correlation matrix (2002-2011, developing countries)

	L	lGOV	$l\tilde{Q}$	OPEN	GCF	GDS	lEF	GOVCONS	lEDUC	lINFRA
L	1.0000									
lGOV	-0.3245	1.0000								
$\tilde{Q}$	0.2237	0.2687	1.0000							
OPEN	-0.1221	0.2471	0.3720	1.0000						
GCF	0.0655	0.0313	0.2916	0.0292	1.0000					
GDS	0.4359	0.0757	0.4968	0.0449	0.3556	1.0000				
lEF	0.0112	0.6391	0.1749	0.1051	-0.2326	-0.0745	1.0000			
GOVCONS	-0.2528	0.0386	-0.0625	0.0899	-0.0120	-0.2598	-0.1613	1.0000		
lEDUC	-0.2671	0.2866	0.1834	0.3291	-0.0948	0.0502	0.0849	0.4265	1.0000	
lINFRA	-0.4690	0.4409	0.2088	0.3626	0.1055	0.1594	0.0979	0.4351	0.7414	1.0000

B.3. Parameters and variables

Table 4.B.3.1: Values of parameters and variables

Parameter	Value	Parameter	Value	Variable	Value
α	0.7	q	1.5	A_N	3.5
σ	3.5	τ_{x_S}	0.01	A_S	3
φ	0.00000025*	β_S	0.6	L_N	5
η	2	ζ_S	2	L_S	6.25
ρ	0.02	MC_N	1	$\tilde{Q}$	0.35
θ	3	MC_S	0.8		

*From Connolly and Valderrama (2005) we know that $\eta = 2$ and which $\varphi = \left(\frac{M}{Q_N}\right)^{\eta}$. As the Northern aggregate quality index, Q_N, is considered to be huge, the ratio will be small, it will be higher than zero but relatively close, then, we consider the ratio equal to 0.0005 and obtain $\varphi = 0.00000025$. In the graph below we can state that the value of the IPR parameter is not much sensitive to changes in the ratio (the graph is done with data of all countries in the period between 1997 and 2011 and data from the 'better specification' for this sample).

Graph 4.B.3.1: The value of the ratio $\frac{M}{Q_N}$

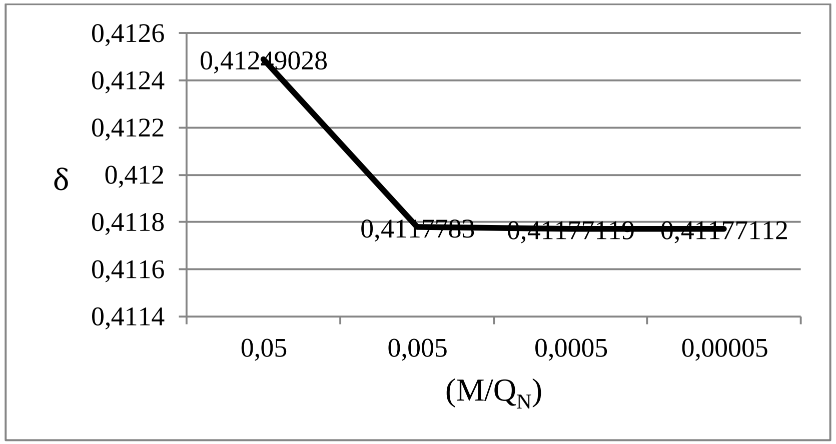

Figure 4.B.3.1. IPR parameter sensibility to (M/Q_N)

Chapter 5

Endogenous growth and intellectual property rights: a North-South modelling proposal with population ageing

5.1. Overview

Population ageing, especially in the most developed countries, has become an important matter in the economic and social debate. In this sense, and according to, for example, Prettner (2009, 2013), this topic has been discussed both in academic approaches and in public forums (see, for instance, Bloom *et al.* 2008, 2010a, 2011; The Economist 2009, 2011).

In accordance with Nagarajan *et al.* (2013), although the increase of longevity and the decrease of mortality rates can be seen as important outcomes of medical science advances, these two facts and the decrease of fertility rates can represent a serious economic problem because they are synonymous of ageing populations in many developed countries (see, for example, Harper and Leeson, 2009). The diminution of population growth is also a reality in several countries and it is mainly justified by the adult working-age population surpassing the child population (see, for instance, Mason and Lee, 2011).

Several works have studied the impact of ageing on economic growth (*e.g.*, Lindh and Malmberg, 2009; Bloom *et al.,* 2010b; Eiras and Niepelt, 2012; Prettner, 2009, 2013). Groezen *et al.* (2005) show that, while in a closed country, the effect of rising longevity on growth can rely on the substitutability of labour and capital, in a small open country ageing unequivocally declines long-run growth. Bloom *et al.* (2010b) state that population ageing decreases labour force participation and saving rates; therefore, the concerns about an eventual reducing of economic growth associated with this phenomenon are increasing. Nevertheless, the authors conclude that this effect may have a discreet impact regarding the decrease of the economic growth rate in OECD countries, but not a devastating effect. Relatively to non-OECD countries, they express that population ageing will not significantly inhibit the economic growth speed in developing countries.

Narciso (2010) also finds a negative relationship between population ageing and economic growth because, according to his study, ageing leads to a decrease in the human capital stock, which, in turn, will impact negatively on economic growth. Also, Eiras and Niepelt (2012), Lisenkova *et al.* (2012) and Walder and Döring (2012) support the negative relationship between population ageing and economic growth, even indirectly. However, this negative relationship is not always advocated. For example, Hazan and Zoabi (2006) show how health and longevity can play an important role in the transition process from stagnation to growth of a certain country. According to Lee *et al.* (2011), a positive effect of ageing on growth is possible when the share of active working age population is higher than the non-working population share (see, also, Cervellati and Sunde, 2005; Prettner, 2009, 2013).

Our main motivation with the present work is to address the impact of ageing on economic growth, by extending Azevedo *et al*. (forthcoming) with the introduction of ageing population (in line with Blanchard, 1985) and, to study whether this change has significant impact on the effect of Intellectual Property Rights (IPR) on economic growth. Moreover, we also extend the model in Azevedo *et al*. (2014) by analysing its functioning in the presence of an additional sector: the health care sector – in line with Kuhn and Prettner (2012).

The rest of the chapter is structured as follows. After these introductory remarks, Section 5.2 presents the setup of the model. Section 5.3 analyses the equilibrium and Section 5.4 concludes.

5.2. Setup of the model

The framework of this study is similar to Azevedo *et al.* (forthcoming) and is also based on Kuhn and Prettner (2012). Bearing in mind these contributions, we describe the fundamental considerations about the model's structure, emphasising the main differences: the changes introduced by considering ageing population and an additional sector, the health care sector.

Following Kuhn and Prettner (2012), we use an overlapping generations structure in the spirit of Blanchard (1985) into a model similar to Romer's (1990), where the R&D investments are the main engine of endogenous economic growth. The economy is constituted by four sectors: final goods sector, intermediate goods sector, R&D sector and health care sector. The sector of final goods, the R&D sector and the health care sector are supposed to operate under perfect competition, while the intermediate goods sector produces under monopolistically competition. Moreover, taking into account Kuhn and Prettner (2012), it is assumed perfect labour mobility in the sectors that use labour: final goods and health care.

Relatively to demographic properties, we consider, such as in Romer's (1990) model, a stationary population which is comprised by several groups of people, identified by their date of birth, t_0. In line with this, we assume that the birth rate (being comparable to the period fertility rate in a certain context) is equal to the mortality rate, μ. At a given moment $t > t_0$, each of these cohorts is composed by an amount of $N(t_0, t)$ agents. Bearing in mind Blanchard (1985) and according to Kuhn and Prettner (2012), we consider that agents face a constant risk of death at each instant, μ, which equals the fraction of the population dying at each moment due to the law of large numbers.

Additionally, it is important to highlight that, although we assume increases in the health care level lead to decreases in the mortality rate which, in turn, mean proportional decreases in the birth rate, this is not consistent with changes in fertility decisions but just with an 'accounting effect'. That is, such as Kuhn and Prettner (2012), we consider that for a constant cohort fertility rate, a reduction in mortality must lead to a one-to-one reduction in period fertility. Moreover, with rising longevity, agents extend a constant number of births through a longer lifespan which implies, statistically, that there are less newborn children at each moment in time and consequently the birth rate is inferior. In fact, this is in line with the evidence which suggests that the decrease in period fertility rates detected over the past years cannot imply a decrease in cohort fertility but can be caused by the postponement of fertility through a lifespan of increasing duration (see, for instance, Bongaarts and Sobotka, 2012).

5.2.1. Consumers

Following Prettner (2009) and Kuhn and Prettner (2012), we assume that the Northern consumer makes consumption and saving decisions in order to maximize the present value lifetime:

$$U = \int_{t_0}^{\infty} u(\bar{c}_N) e^{-(\rho+\mu_N)(m-t_0)}\, dm \tag{5.1}$$

where,

$$u(\bar{c}_N) = \left(\frac{\bar{c}_N^{1-\theta}-1}{1-\theta}\right), \tag{5.2}$$

$$\bar{c}_N = c_N^{\hbar} {c_S}^{f\,1-\hbar}. \tag{5.3}$$

s.t.

$$\dot{a}_N = (r_N + \mu_N - \gamma)a_N + (1 - \Gamma)w_N l_N + d_N - expend_N - p_{H_N}\vartheta h_N \tag{5.4}$$

where,

$$expend_N = P_N c_N + P_S^f c_S^f. \tag{5.5}$$

We use a constant intertemporal elasticity of substitution (CIES) instantaneous utility function, $u(\bar{c}_N)$, where $\bar{c}_N$ denotes the Northern composite good, θ refers to the inverse intertemporal elasticity of substitution and $\rho > 0$ represents the homogeneous subjective discount rate. Equation (5.3) is a Cobb-Douglas aggregator that defines the Northern composite good, $\bar{c}_N$, in terms of Northern and Southern final goods, c_N and c_S^f, respectively, both consumed in the North (f means foreign or exports). In the same equation, parameter κ corresponds to domestic expenditure-share.

The set of expressions (5.1)-(5.5) present the modified individual's lifetime utility and the modified budget constraint (the path of the value of assets) where t_0 corresponds to the date of birth of a given generational group and $\mu \geq 0$ refers to the mortality rate. This last rate increases the discount rate of agents because individuals face the risk of death and, hence, they postpone consumption lesser than in the case of lifetime certainty. Similarly to Prettner (2009, 2013), we assume that, within a given cohort, the wealth of dead agents is redistributed by those who survived. Consequently, the real rate of return is increased by the mortality rate. We also consider that there is a tax on labour income similar to contributions for social security applied by the government. Below, when describing the health care sector, we stress how the public share of health care is supported by this tax.

According to Kuhn and Prettner (2012), in the consumers' problem we assume that the agents expend their earnings both on consumption and on private health care. In the wealth constraint, expression (5.4), a denotes the individual assets stock, r_N is the return of the assets and $\gamma \geq 0$ refers to the rate depreciation; wl represents the agent's (yearly) wage income, where w is the wage rate and l is the agent's inelastic yearly labour supply (similarly to Papageorgiou, 2002, with the human capital, we establish

$l = l_Y + l_H$ where l_Y and l_H are the fractions of workers allocated to the production of the final good and to the health sector); $\Gamma \in [0,1]$ denotes the tax on labour income; d is the earnings from dividends (net of new investments); $expend_N$ refers to Northern consumption expenditures (which can be defined as $expend_N = \bar{c}_N \bar{P}_N$ as it is possible to deduce through the equations presented in Connolly and Valderrama, 2005 – see Appendix C.1.); and $p_H \vartheta h$ represents the private health care payments, where p_H is the unit price, h denotes the total amount of health care and $\vartheta \in [0,1]$ refers to the private finance share.

Solving the maximization problem, we obtain the following individual Euler equation:

$$\frac{\dot{\bar{c}}_N}{\bar{c}_N} = \hat{\bar{c}}_N = \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right), \tag{5.6}$$

which allows us to conclude that the consumption only grows when the rate of return on assets surpasses the sum of the capital depreciation rate, the price growth and the subjective time discount rate.

In the South, the problem is symmetric.

5.2.2. Aggregate capital stock and aggregate consumption

The individual Euler equation presented in equation (5.6) is similar to the one that emerged in the case with no lifetime uncertainty as in Azevedo *et al*. (forthcoming). Nevertheless, in the present setting we assume, not just a representative agent, but rather individuals are considered to be heterogeneous relatively to age and wealth accumulation because elderly people has more time to accumulate positive capital. Then, we employ some aggregation rules (following Prettner, 2009, 2013 and Kuhn and Prettner, 2012; see also Heijdra and van der Ploeg, 2002) to obtain the law of motion for the aggregate capital and to the economy-wide ("aggregate") Euler equation:

$$\mathcal{A}(t) \equiv \int_{-\infty}^{t} a(t_0, t) N(t_0, t) dt_0, \tag{5.7}$$

$$\bar{C}_N(t) \equiv \int_{-\infty}^{t} \bar{c}_N(t_0, t) N(t_0, t) dt_0, \tag{5.8}$$

where $\mathcal{A}(t)$ refers to the aggregate capital. Considering that, with a constant population, each generational group has the size $\mu N e^{\mu(t_0-t)}$ at a given point of time $t > t_0$, and that, at time t, total population size is given by $\int_{-\infty}^{t} \mu N e^{\mu(t_0-t)} dt_0$, we obtain:

$$\mathcal{A}(t) \equiv \mu N \int_{-\infty}^{t} a(t_0, t) e^{\mu(t_0-t)} dt_0, \tag{5.9}$$

$$\overline{C}_N(t) \equiv \mu N \int_{-\infty}^{t} \overline{c}_N(t_0, t) e^{\mu(t_0-t)} dt_0. \tag{5.10}$$

After some mathematical operations (see Appendix C.2.), and similarly to Kuhn and Prettner (2012), we arrive at the expressions for the Northern law of motion of the aggregate capital and for the Northern aggregate Euler equation:

$$\dot{\mathcal{A}}_N = (r_N - \gamma)\mathcal{A}(t) - E_N(t) + (1 - \Gamma)W_N(t) + D_N(t) - p_{H_N}\vartheta H_N, \tag{5.11}$$

$$\frac{\dot{\overline{C}}_N}{\overline{C}_N} = \hat{\overline{C}}_N = \frac{1}{\theta}\left(r_N - \rho - \frac{\dot{\overline{P}}_N}{\overline{P}_N} - \gamma\right) - \mu_N \Lambda_N, \tag{5.12}$$

where $E_N(t)$, $W_N(t)$, $D_N(t)$ and H_N refers to Northern aggregate expenditures, aggregate labour income, aggregate (net) dividends and aggregate health care consumption, respectively; $\Lambda_N = \frac{\overline{C}_N(t) - \overline{C}_N(t,t)}{\overline{C}_N(t)} \in [0,1]$. By observing the above expression, we can verify that the aggregate Euler equation differs from the individual Euler equation in the term $-\mu_N \frac{\overline{C}_N(t) - \overline{c}_N(t,t)N}{\overline{C}_N(t)} \in [-\mu, 0]$.

As the consumption of the newborns, $\overline{C}_N(t,t)$, is always lower than aggregate consumption, $\overline{C}_N(t)$, individual consumption growth will be higher than aggregate consumption growth. A possible explanation for this is that, at each moment, a proportion μ of elder and richer agents die and are substituted by poorer newborns. Since these individuals can barely afford consumption comparing with the eldest, the aggregate consumption growth, as compared to individual consumption growth, is slowed by the replacement of generations (see also Heijdra and van der Ploeg, 2002). Moreover, such as Kuhn and Prettner (2012), we assume the term Λ is constant over time because it can be written as

$$\Lambda_N = (\rho + \mu_N)\frac{\mathcal{A}_N(t)}{\overline{C}_N(t)\overline{P}_N} \tag{5.13}$$

(see Appendix C.2.), which is constant when the aggregate financial wealth, $\mathcal{A}_N(t)$, grows at the same rate as the aggregate Northern consumption expenditures, $\overline{C}_N(t)\overline{P}_N = E_N(t)$.

5.2.3. Health care sector

Bearing in mind Kuhn and Prettner (2012), we consider that, in the health care sector, health care is obtained from labour according to the following production function:

$$hN = L_H, \tag{5.14}$$

in which h denotes the *per capita* health care, N is the size of the population and L_H represents the aggregate employment in the health care sector. Equivalently, we can write $h = \frac{L_H}{N}$ and so, we can state that *per capita* consumption of health care is increasing when employment in the health care sector also rises. In this sense, an upper bound on the consumption of health care *per capita* appears for the constraints $L_H \leq L \leq N$, here L is the size of the available labour force: $h_{max} = \frac{L}{N} \leq 1$. The idea behind the constraints is intuitive and easy to understand: the supply of health care cannot exceed a degree at which the health care sector uses total labour force.

We also assume that the mortality rate is diminishing in the *per capita* annual level of health care, h, and thus we write the mortality rate as $\mu(h)$. In line with this, we consider:

$$\mu(0) = \overline{\mu} \in (0, \infty),\ \mu(h_{max}) = \underline{\mu} \in [0, \overline{\mu}), \tag{5.15}$$

$$\mu' \leq 0,\ \mu'' \geq 0,\ \mu''' \leq 0, \tag{5.16}$$

which suggests that, by increasing the health care, the mortality rate can decrease from a maximum $\overline{\mu}$ to a minimum $\underline{\mu} \geq 0$. The minimum is achieved when we are in the presence of the maximum attainable level of health care, h_{max}, that is, where the health care sector uses total available labour.[47] We also consider that health care is subject to diminishing returns though in a weak way. We assume that health care reduces not only the mortality rate but also the rate of incidence of a disease, which enables agents to rise their annual effective labour supply, $l(h)$. In particular, we consider that:

$$0 \leq l(0) \leq l(h_{max}) = h_{max} \leq 1, \tag{5.17}$$

$$l' \geq 0,\ l'' \leq 0,\ l''' \geq 0. \tag{5.18}$$

[47] The effect of health care on mortality or on longevity is empirically supported by, for example, Lichtenberg (2004) and Cutler *et al*. (2006).

According to the above considerations, the supply of labour *per capita* rises with the health care degree at weakly decreasing returns. Moreover, if we consider that agents provide the same quantity of labour in spite of their age[48] we can express the total supply of labour as:[49]

$$L = l(h)N. \tag{5.19}$$

Now, it is simple to state that the constraint $L_H \leq L \leq N$ entails $h \leq l(h) \leq l(h_{max}) = h_{max} \leq 1$.[50]

Another feature of this sector is the funding of health care. Continuing in the line of Kuhn and Prettner (2012), we consider $\vartheta \in [0,1]$ as the private finance share in the health care sector and $(1-\vartheta)$as the public share which is financed by a tax on labour income that is equivalent to a social security contribution. Hence, the aggregate health expenditure, denoted by G, is given by

$$wL_H = G = p_H \vartheta H + \Gamma W. \tag{5.20}$$

The left hand side of the above equation describes the health care expenditure, $wL_H = whN$. The right hand side presents the composition of funding in health care, where $p_H \vartheta H = p_H \vartheta hN$ denotes the amount of private finance and $\Gamma W = \Gamma w l(h) N$ is the public finance. Following Kuhn and Prettner (2012), we assume that the public health care budget is balanced at each moment. Once we consider that the health care sector works under perfect competition, $p_H = w$ which allows us to rewrite the expression (20) as $h = \vartheta h + \Gamma l(h)$, and solving it for the tax rate we obtain $\Gamma = \frac{(1-\vartheta)h}{l(h)} \in [0,1]$. Observing this expression, we conclude that the *per capita* supply of health care, h, and the public share, $(1-\vartheta)$, affect positively the tax while the *per capita* provision of labour have a negative impact. According to Kuhn and Prettner (2012), by assuming a competitive health care sector and a non-distortionary tax, economic growth is not affected by the mode of health care funding, that is, economic

[48] The mortality rate is independent of age.
[49] Similarly to Kuhn and Prettner (2012), at the aggregate level, we can denote $l(h)$ as the percentage of population that can work full time or as the average time at work, where agents may differ in their provision of labour relying on whether or not they are healthy or ill.
[50] If $l(h)$ is not a measure of participation but of productivity, it is understandable that $l(h_{max}) = h_{max} > 1$. However, Kuhn and Prettner (2012) ignore this case without loss of generality.

growth is determined by the size of the health care sector, measured by h, but not by how health care is financed as we can verify on onward.

5.2.4. Final goods sector

We assume that the final good, Y, is produced under perfect competition and it can be produced in the North and in the South according to

$$Y_i(t) = A_i L_{Y,i}{}^{\alpha} \sum_{j=1}^{J} \left(q^{k_N(j,t)} x_i(j,t)\right)^{1-\alpha}, i \in \{N,S\}, \tag{5.21}$$

where A_i is an exogenous productivity level which relies on the country's institutions (we consider $A_N > A_S$); $L_{Y,i}$ denotes the labour input used in the final goods production and $\alpha \in [0,1]$ refers to the share of labour; $q^{k_N(j,t)} x_i(j,t)$ represents the quality adjusted intermediate good j in the moment t, $q > 1$ is a constant fixed exogenously, which expresses the size of each quality improvement reached by each successful R&D activity, k denotes the steps of the quality ladder (a higher quality is indicated by a higher k), $x_i(j,t)$ refers to the quantity of intermediate good used in the final good production; and $(1-\alpha)$ is the aggregate factor share of the intermediate goods.

In both countries, given the price of the final good i, $p_i(t)$, and the price of the intermediate good j, $p(j,t)$, the implicit demand for each intermediate good by the representative final good producer is:

$$x_i(j,t) = L_{Y_i} \left[A_i(1-\alpha)\frac{p_i(t)}{p(j,t)}\right]^{\frac{1}{\alpha}} q^{k_N(j,t)\left[\frac{1-\alpha}{\alpha}\right]}. \tag{5.22}$$

Putting this expression into the equation (5.21), replacing $p_i(t)$ by the marginal cost, MC_i, and $p(j,t)$ by the limit prices reported in the next subsection, the final goods supply in the North and in the South is, respectively:

$$Y_N(t) = A_N^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_{Y,N} Q_N \left[n_{NN} + n_{NS}\left(1+\tau_{x_S}\right)^{\frac{\alpha-1}{\alpha}} MC_S^{\frac{\alpha-1}{\alpha}} + n_S q^{\frac{1-\alpha}{\alpha}}\right], \tag{5.23}$$

$$Y_S(t) = A_S^{\frac{1}{\alpha}} \left(\frac{1-\alpha}{q}\right)^{\frac{1-\alpha}{\alpha}} L_{Y,S} Q_N \left[n_{NN}\left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}} + n_{NS} + n_S q^{\frac{1-\alpha}{\alpha}} \left(\frac{MC_S}{1+\tau_{x_S}}\right)^{\frac{1-\alpha}{\alpha}}\right], \tag{5.24}$$

$$Q_N = \sum_{j=1}^{J} q^{\frac{k_N(j,t)(1-\alpha)}{\alpha}}. \tag{5.25}$$

From the expressions above, we can verify that the aggregate production in both economies depends on Q_N (the Northern aggregate quality index) because the limit pricing with free trade ensures that only the highest technology will be used. Therefore, even in the case in which an intermediate good is produced in the North, its quality degree is the same as the top Northern quality level.

As we consider that the final good is produced under perfect competition, that is, its price is equivalent to its marginal cost, the marginal cost of producing an intermediate good is independent on its stage of quality and is comparable among all internal sectors. Normalizing the Northern marginal cost to one ($MC_N = 1$), we assume that $MC_N > MC_S$.

5.2.5. Intermediate goods sector

In line with Azevedo *et al.* (forthcoming), we consider that both the technological level and the trade barriers of each country define which one produces the intermediate goods used in the final goods production. Since the North is assumed as the most technologically advanced economy, it is expected to innovate, promoting world technological frontier. Regarding the South, we consider that, by imitating the Northern technology, it can raise its domestic technology level (this may occur until the gap in technological levels is abolished). Moreover, we assume that when a country knows how to produce an intermediate good, it can be produced using the production function of the final goods. In this sense, the marginal cost of producing an intermediate good and the marginal cost of producing the final good, MC_i, are equal and we assume that $0 < MC_S < MC_N = 1$, allowing the Southern economy to produce the same quality degree, k, but at a price lower than that charged by its competitor (Northern country). Thus, it is possible for a successfully imitating Southern firm to capture the world market.

We also suppose that the knowledge of how to produce a good is domestically free and that the domestic IPR are protected (the innovator is internally protected by a system of domestic IPR). In our model we are particularly focused on international IPR which protect the innovator economy from foreign imitation; then, when we refer to IPR protection we mean international IPR protection.

Bearing in mind Azevedo *et al.* (forthcoming) and the demand equation (5.22), the profits of monopolist intermediate goods firms are maximized throughout the optimal price, given by the following mark-up:

$$p(k,j,t) = p(j,t) = p = \frac{1}{1-\alpha}, \qquad (5.26)$$

which is constant over time, across firms and for all quality levels. The mark-up becomes lower when α is nearer to zero and, hence, less opportunity there is for monopoly pricing.

The expected profits are influenced by how the firms compete. Besides, there are three types of firms: Northern firms challenging Northern competition, n_{NN} , Northern firms facing Southern competition, n_{NS}, and Southern imitation firms (which always face Northern competition), n_S. By assumption, there are J sectors and the sum of these percentages is equal to $J\ (=1)$. As each type of firm can have both national and international sales, we find six limit prices. Northern firms facing Northern rivalry fix a limit price slightly below q times the lowest price at which the former innovator could sell, because the good is q times more productive than the previous. As MC_N=1 is the lowest price at which the precursor innovator could sell in the North and $(1+\tau_{x_S})$ is the lowest price at which the good could be sold in the South, since it is subject to Southern tariffs on intermediates goods and *ad-valorem* transportation costs, τ_{x_S}, Northern firms challenging Northern competition, n_{NN}, select two limit prices: $P_{NN} = qMC_N = q$ for internal sales and $P_{NN}^f = q(1+\tau_{x_S})$ for Southern sales.[51] At these prices, world sales of all obsolete technologies will disappear. In the same way, Northern firms facing Southern competition, n_{NS} , choose limit prices $P_{NS} = qMC_S(1+\tau_{x_S})$ for national sales and $P_{NS}^f = qMC_S$ internationally. Southern firms, n_S, always challenge Northern competition and fix limit prices $P_S^f = 1$ for foreign countries and $P_S = 1+\tau_{x_S}$ for national sales.

5.2.6. R&D sector

Similar to the framework of Azevedo *et al*. (forthcoming), the R&D sector assumes a central role in the analysis. We consider that firms choose the quantity of resources to

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[51] "This holds if $q(1-\alpha) \leq 1$. If instead, $q(1-\alpha) > 1$, then Northern firms will use monopoly pricing" (Connolly and Valderrama, 2005: 13).

employ, according to the expected present value of profits from successful research, which relies on the probabilities of innovation and imitation. From Northern R&D activities emerge innovative blueprints for manufacturing intermediate goods, improving their quality. In an intermediate goods sector *j*, presently at quality degree $k_N(j,t)$, $I_N(j,t)$ denotes the probability at moment *t* that the $(k_N(j,t)+1)^{\text{th}}$ innovation will occur and will follow a Poisson process. In the same way, we also assume that IPR protect domestically these designs and that the top firm in each *j* (that is, the one producing according to the latest patent) applies limit pricing to ensure monopoly. The probabilities of successful innovation and imitation are crucial for R&D, as the income from profits during each moment *t* to the monopolist and the duration of the monopoly power provide to the value of the top patent. These probabilities creatively remove either the existing lead design (*e.g.*, Aghion and Howitt, 1992) or the Northern production (*e.g.*, Grossman and Helpman, 1991a, Ch. 12) affecting the monopoly duration. For simplicity, an important feature of our model is associated with R&D technology: we assume that there is a positive effect of a healthy population on labour supply, which positively impacts on the probability functions of innovation and imitation $L_{Y,i}$ (for example, Bloom *et al.*, 2004 show a positive effect of health on economic growth). In this line, we present the following probabilities of innovation and imitation, respectively:

$$I_N(j,t) = y_N(j,t)\beta_N q^{k_N(j,t)}{\zeta_N}^{-1} q^{-\alpha^{-1}k_N(j,t)} {L_{Y,N}}^{\Psi}, \tag{5.27}$$

$$I_S(j,t) = \ y_S(j,t)\beta_S q^{k_S(j,t)} \frac{e^{\varphi}}{\zeta_S \tilde{Q}^{\sigma}} q^{-\frac{k_N(j,t)}{\alpha}} \ \frac{1}{\delta}\left(\frac{1}{\tilde{Q}}\right)^{1-\delta} {L_{Y,S}}^{\Psi}, \tag{5.28}$$

where $y_i(j,t)$ is the flow of final good resources in the country i allocated to R&D in j, which defines our setup as a lab equipment model (*e.g.*, Rivera-Batiz and Romer, 1991); $\beta_i q^{k_i(j,t)}$denotes the learning by previous domestic R&D as a favourable learning effect because of the accumulated public knowledge from previous successful R&D (*e.g.*, Grossman and Helpman, 1991a, Ch. 12; Connolly, 2003) and we assume that $\beta_N > \beta_S > 0$ and $k_N > k_S$, that is, we consider that the effect of learning-by-past innovations is higher than the one associated with learning-by-past imitations; ${\zeta_i}^{-1} q^{-\alpha^{-1} k_N(j,t)}$ describes the adverse effect caused by the increasing complexity of quality improvements (or the complexity cost) and it is supposed that $\zeta_N > \zeta_S$, that is, the innovation cost is higher than the fixed cost of imitation (Mansfield *et al.*, 1981); and, finally, $L_{Y,i}$ denotes employment in the final goods sector in the country i, with $\Psi > 0$ but close to zero. In the probability of imitation, besides the fixed cost of imitation, ζ_S, the imitation cost also depends on the sector j South/North ratio, $\tilde{Q} = \frac{q^{k_S(j,t)} * J}{q^{k_N(j,t)} * J} = \frac{QS}{QN} = \hat{q}_j$ ($\sigma > 1$ refers to how fast the cost of imitation rises as the technology gap decreases) and on the interaction between the two countries, with φ (e^{φ} revealing lower costs of collecting information about goods from abroad with more interaction between the two economies, whereas the interaction is measured by the ratio between Southern openness to intermediate goods imports, M, and the aggregate Northern technology level, Q_N). Moreover, $\delta \in [0,1]$ measures the degree of Southern IPR protection and in accordance to Azevedo *et al.* (forthcoming), we introduce the IPR effect in two ways:

(i) we fix a negative relationship between the IPR parameter, δ, and the probability of imitation, $I_S(j,t)$: the higher δ, the higher the level of Southern IPR enforcement and the lower the probability of successful imitation;

(ii) we consider that the lower the distance from the technological frontier (the greater $\tilde{Q}$), more IPR laws will be applied by these countries and, then, the lower the probability of imitation (because, generally, developed countries have higher levels of IPR protection: Lai and Qiu, 2003; Grossman and Lai, 2004; Naghavi, 2007; Dinopoulos and Segerstrom, 2010).

Assuming that $L_i = L_{Y,i} + L_{H,i}$ and knowing that $L_i = l_i(h_i)N_i$ and $L_{H,i} = h_i N_i$, we obtain $L_{Y,i} = l_i(h_i)N_i - h_i N_i$. Now, we can rewrite the probability functions of successful innovation and imitation, respectively, as:

$$I_N(j,t) = y_N(j,t)\beta_N q^{k_N(j,t)} {\zeta_N}^{-1} q^{-\alpha^{-1} k_N(j,t)} (N_N[l_N(h_N) - h_N])^{\Psi} \tag{5.29}$$

$$I_S(j,t) = y_S(j,t)\beta_S q^{k_S(j,t)} \frac{e^{\varphi}}{\zeta_S \tilde{Q}^{\sigma}} q^{-\frac{k_N(j,t)}{\alpha}} \frac{1}{\delta} \left(\frac{1}{\tilde{Q}}\right)^{1-\delta} (N_S[l_S(h_S) - h_S])^{\Psi} \tag{5.30}$$

5.3. Equilibrium

The equilibrium conditions, namely in the equilibrium R&D, are similar to those described in Azevedo *et al*. (forthcoming). Consequently, in this section, we underline essentially the main differences.

5.3.1. Equilibrium R&D

Bearing in mind the probabilities of successful R&D, which depend on the resources (composite final goods) allocated to it, entry equilibrium is described by the equality between the expected return and the consumption of resources. In the case of imitation, this equality is represented by:

$$I_S(k,j,t)V_S(k,j,t) = y_S(j,t) \tag{5.31}$$

where $V(k,j,t)$[52] is the expected current value of the flow of profits to the producer of j, which relies on the profits at t, $\Pi_S(k,j,t)$, on the equilibrium interest rate and on the expected duration of the flow (*i.e.* expected duration of research leadership). $\Pi_S(k,j,t)$ relies on $MC_N = 1$, MC_S, $P_{NN}(j)$, $P_{NS}(j)$, $x_N(k,j,t)$ and $x_S(k,j,t)$ and, hence, on trade. For instance, $I_N(k,j,t)$, which is the potential competitor, depends on the expected duration of the imitator's technological-knowledge leadership, as the Southern entrant competes with a Northern incumbent. Consequently, $V_S(k,j,t)$ is:

$$V_S(k,\bar{j},t) = \int_t^{\infty} \Pi_S(k,\bar{j},t)\, exp\left[-\int_t^{s}(r_S(v) - \gamma + I_N(k,\bar{j},v))dv\right]ds \tag{5.32}$$

where $\Pi_S(k,j,t)$ using an imitation of the quality k is represented by:

[52] *I.e.*, $V(k, j, t)$ is the market value of the patent or the value of the monopolist firm, owned by consumers.

$$\Pi_S(k,\bar{j},t) = (1-\alpha)^{\alpha^{-1}} q^{k_N(j,t)(1-\alpha)\alpha^{-1}} B(t) \tag{5.33}$$

where $B(t) = (1-MC_S)L_{Y,N}(t){A_N}^{\alpha^{-1}} + \left(1+\tau_{x_S} - MC_S\right)L_{Y,S}(t)\left(A_S \frac{MC_S}{1+\tau_{x_S}}\right)^{\alpha^{-1}}$.

Differentiating equation (5.32) by applying Leibniz's rule, we achieve the dynamic arbitrage equation:

$$r_S(v) - \gamma + I_N(k,\bar{j},v) = \frac{\dot{V}_S(k,\bar{j},t)}{V_S(k,\bar{j},t)} + \frac{\Pi_S(k,\bar{j},t)}{V_S(k,\bar{j},t)} - \dot{k}(\bar{j},t)\left(\frac{1-\alpha}{\alpha}\right) ln\, q \tag{5.34}$$

If we insert equation (31) into the free entry R&D equilibrium condition, $I_S(j,t)V_S(j,t) = y_S(j,t)$, and if we solve it for I_N, we get the equilibrium probability of successful innovation. As the probability of successful innovation determines the technological knowledge progress, equilibrium can be translated into the path of Northern technological knowledge, from which free trade in intermediate goods allows the South to benefit, as well. The relationship ends up to generate the expression, where I_N is included, for the equilibrium growth rate of the aggregate Northern technological level, Q_N:

$$\hat{Q}_N = I_N\left(q^{(1-\alpha)\alpha^{-1}} - 1\right). \tag{5.35}$$

5.3.2. Steady state

The steady state growth rate must be the same in both countries because, by assumption, both economies access through free trade to the same state-of-the art intermediate goods and have the same technology of final goods production, which suggests, through the Euler equation (5.12), that interest rate as well as the term $\mu\Lambda$ are also equalized between economies in steady state, $\mu_N\Lambda_N = \mu_S\Lambda_S \equiv \mu^*\Lambda^*$.[53] Moreover, as in Afonso

[53] We state above that Λ is constant if the aggregate capital grows at the same rate as the aggregate Northern consumption expenditures. Then, as the mortality rate is supposed to be higher in the South (developing countries), $\mu_N < \mu_S$, the constant $\Lambda = (\rho + \mu_i)\frac{\mathcal{A}(t)}{\bar{C}_i(t)\bar{P}_i}$ must be higher in the North (and as Λ also depends positively on μ_i, $\Lambda_N > \Lambda_S$ implies that $\frac{\mathcal{A}_N(t)}{\bar{C}_N(t)\bar{P}_N} > \frac{\mathcal{A}_S(t)}{\bar{C}_S(t)\bar{P}_S}$).

(2012), we define, generically, the instantaneous aggregate resources constraint as $Y_S(t) = \bar{C}_S(t) + H_S + X_S(t) + R_S(t)$, where: $Y_S(t)$ denotes total resources, the composite final good; $\bar{C}_S(t)$ is aggregate consumption; H_S refers to aggregate health care consumption; $X_S(t)$ represents aggregate intermediate goods; $R_S(t)$ is total resources employed in R&D. That is, we assume that, each aggregate final good can be consumed or saved (and used for purchase health care, for R&D or transformed into intermediate goods). This implies that steady state growth rate of these variables will be equal to the growth rate of Northern technological knowledge. Therefore, there is a growth rate constant and shared by both countries, g^*,

$$g^* = \hat{Q}_N^* = \hat{Y}_N^* = \hat{Y}_S^* = \hat{X}_N^* = \hat{X}_S^* = \hat{R}_N^* = \hat{R}_S^* = \hat{H}_N^* = \hat{H}_S^* = \hat{\bar{C}}_N^* = \hat{\bar{C}}_S^* = \frac{1}{\theta}(r^* - \rho - \gamma) - \mu^* \Lambda^*. \qquad (5.36)$$

In particular $\hat{\tilde{Q}}^* = 0$ and sector shares, n_{NN}, n_{NS} and n_S, are constant.

Thus the steady state growth rates of both countries rely only on Northern technological progress, while the North stays the leading innovator. Furthermore, international trade and the risk of losing the market for a particular intermediate good to Southern imitation infers that the Northern rate of innovation relies on the Southern rate of imitation.

In steady state, $\frac{\dot{V}_S(k,\bar{J},t)}{V_S(k,\bar{J},t)} = \dot{k}(\bar{J},t)\left(\frac{1-\alpha}{\alpha}\right)\ln q$ and thus, taking into account equation (30), equation (34) becomes:

$$I_N^* = \beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} B^* (N_S[l_S(h_S) - h_S])^{\Psi} - r^* + \gamma \qquad (5.37)$$

Equation (5.37) demonstrates that the available (or Northern) technological knowledge progress:

(i) relies on innovation earnings which, in turn, depend on I_S and $\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma}$, through inter country competition in intermediate goods. That is, the positive level effect from North to South (the access to the lead quality intermediate goods rises production and, therefore, the resources to imitative R&D) feeds back into North, influencing Q_N by creative destruction;

(ii) does not depend on its scale, as it is not influenced by the stage of quality k. Actually, the positive effect of the quality stage on profits and on the learning effect is precisely compensated by the negative effect on the complexity cost;[54]

(iii) relies on market size effects;

(iv) depends on the labour employed in the Southern final goods production, $L_{Y,S} = l_S(h_S)N_S - h_S N_S$, which, in turn, relies on the consumption of health care *per capita*, h_S. That is, the higher the health care in the South, the more healthy population is available to produce final goods. This will have a positive impact on the resources to imitative R&D, which will affect the Northern R&D activity.

As far as equations (5.35), (5.36) and (5.37) are concerned, we can obtain the steady state interest rate: firstly, we consider equation (5.37) into equation (5.35) substituting I_N, then we use equation (5.36) into the resulting expression substituting $\hat{Q}_N^*$ and, finally, we solve this in order to r^*. Actually, as steady state prices of non-tradable and tradable goods are constant as well as the growth rate of available technological knowledge, see (5.35) and (5.37), the steady state interest rate shared by both countries, r^*, is obtained:

$$r^* = \frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\,\delta-\sigma} (1-\alpha)^{\alpha^{-1}} B^* Z^*\right\} \left(q^{(1-\alpha)\alpha^{-1}} - 1\right) + \frac{1}{\theta}(\rho+\gamma)}{q^{(1-\alpha)\alpha^{-1}} - 1 + \frac{1}{\theta}}, \qquad (5.38)$$

[54] This is crucial for a symmetric equilibrium (on asymmetric equilibrium in quality ladder models and its growth consequences, see Cozzi *et al.*, 2007).

where $Z = (N_S[l_S(h_S) - h_S])^{\Psi}$. Considering this expression in the Euler equation, we obtain the equilibrium growth rate in the presence of population ageing:

$$g^* = \frac{1}{\theta}\left[\frac{\left\{\beta_S \frac{e^{\varphi}}{\zeta_S \delta} \tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}} B^* Z^*\right\}\left(q^{(1-\alpha)\alpha^{-1}}-1\right)+\frac{1}{\theta}(\rho+\gamma)}{q^{(1-\alpha)\alpha^{-1}}-1+\frac{1}{\theta}} - \rho - \gamma\right] - \mu^* \Lambda^*. \tag{5.39}$$

.

Now, differentiating the previous expression in order to δ, the IPR parameter, we obtain the same sign which we obtained in the absence of population ageing. Moreover, the magnitude of the IPR effect on the growth rate remains almost the same because, despite of the fact that now it depends on the term Z^*, which relies on N_S, l_S, h_S and Ψ, as the parameter Ψ is, by assumption, higher but close to zero, Z^* will be approximately one.

If we differentiate the steady state growth rate with respect to μ^*, the mortality rate, we obtain $-\Lambda^*$. As stated above, $-\mu^*\Lambda^* \in [-\mu^*, 0]$, so we can show that $-\Lambda^* \in [-1,0]$ or, alternatively, $\Lambda \in [0,1]$ and, thus we conclude that when the mortality rate decreases (due to, for instance, an increase in health care *per capita*), the steady state growth rate increases, that is, there is a negative relationship between the mortality rate and the steady state growth rate. In other words, as a decrease in the mortality rate means an increase in longevity, we achieve a positive effect of population ageing on steady state growth rate. According to Prettner (2009), the intuition behind this result suggests that a reduction in mortality rate allows an expansion of the planning horizon of the agents. Therefore, individuals have more time to pay off the investments in new technologies which leads the agents to apply less of their income to current consumption and more to investment in new technologies. However, as this demographic change has a positive effect on growth, the rise in lifetime consumption overcompensates individuals for the initial sacrifice.

Moreover, differentiating the expression of the steady state growth rate in order to h, the health care *per capita*, remembering that the mortality rate relies on the degree of health care *per capita* and is fixed as $\mu(h)$, we obtain the following expression:

$$\frac{\partial g^*}{\partial h} = \frac{1}{\theta}\left[\frac{\left\{\beta_S \frac{e^{\theta}}{\zeta_S \delta} \tilde{Q}^{*\delta-\sigma}(1-\alpha)^{\alpha^{-1}} B(t)\right\}\left(q^{(1-\alpha)\alpha^{-1}}-1\right)+\frac{1}{\theta}(\rho+\gamma)}{q^{(1-\alpha)\alpha^{-1}}-1+\frac{1}{\theta}} \Psi (N_S[l_S(h_S) - h_S])^{\Psi-1} N_S({l_S}' - 1) - \mu^{*\prime}\Lambda^*\right] \tag{5.40}$$

which will be definitely positive if $l'(h) > 1$ (given that, as mentioned above $l' \geq 0$ and $\mu' \leq 0$, that is, the effective labour supply increases in the presence of health care improvements and the mortality rate decreases when the health care is well provided). That is, $l'(h) > 1$ is a sufficient condition for enhancing growth. This result is in line with Kuhn and Prettner (2012) since these authors point out that the growth rate raises in the presence of good health care in the case in which the further supplies do not create a decline in the effective labour supply.

5.4. Concluding remarks

The consequences of population ageing have been widely discussed on several fields of society. In particular, ageing can have some impacts in several economic matters. Nevertheless, the effect of this demographic reality on growth is not clear.

In this chapter, we developed a North-South endogenous growth model in order to understand the impact of population ageing on growth. Moreover, we aimed to understand whether, in the presence of population ageing, there is any change in the IPR effect on growth. Using a brief account of the literature on population ageing (and growth) as motivation, we concluded that there is no consensus about this effect. Our model also provides an explanation for the relationship between health care and economic growth based both on the allocation of labour across two sectors (final goods and health care sector) and by reflecting on R&D sector the health care effect on effective labour supply, given that it is expected that healthy population is more available to work, which, in turn, has a positive impact on the probability of successful R&D.

One of our findings is that, relatively to Azevedo *et al*. (forthcoming), population ageing do not affect the IPR effect on growth, at least in terms of sign because the amplitude of the effect can change, although weakly.

We also found that, regarding mortality rate, it has a negative impact on growth. In other words, there is a positive effect of longevity on growth, which in turn, means that population ageing affects growth positively. This result is not in line with those which advocate that population ageing is negative for economic growth, but it is in line with those that show it is possible a positive effect of ageing on growth.

We also analysed the health care effect on growth and we found that the health care level has a positive impact on growth when additional provisions of health do not cause a decrease in the effective labour supply but increase it in the same or higher magnitude.

In this sense, from the model assumptions and the two last findings, we can conclude that although health care raises longevity and labour supply, increases in health care level will enhance definitively growth when lead to increases in labour supply in the same or higher amplitude.

We are not able to conclude anything concrete whether the steady state growth rate is lower or higher when mortality is present, compared to the standard case of no mortality and infinite planning horizons, because now it depends negatively on the mortality rate (more precisely, on $\mu\Lambda$), but it is also affected by other variables whose value is unknown and it can be negative or positive.

This analysis leaves a number of open questions. Although it allows us to conclude a positive effect of both ageing population and health care on growth, it occurs under some conditions. Moreover, we only study the steady state and our conclusions are very much based on comparative statics so it will be useful to study the transitional dynamics. Another interesting matter to future research is to understand the effect of growth on health care provisions. For instance, we theoretically assume that Northern (developed) countries have higher levels of health care but these countries may not have necessarily higher growth rates. Moreover, it would be useful not only to introduce health care effects by other means (besides or instead of labour) but also to make health care provisions depend on R&D (and IPR) because higher health care provisions are associated with medical and scientific developments (as well as new drugs are oftentimes protected by IPR).

Appendix C

C.1. Proof that $\boldsymbol{expend_N = \bar{P}_N \bar{c}_N}$

To verify that $expend_N = \bar{P}_N \bar{c}_N$, we can use the expression (5.5) and the expressions which define c_N and c_S^f. Similarly to Azevedo *et al*. (forthcoming), we can assume $c_N = \hbar \frac{\bar{P}_N}{P_N} \bar{c}_N$ and $c_S^f = (1-\hbar) \frac{\bar{P}_N}{P_S^f} \bar{c}_N$, respectively. Then, by using the last equations into the expression (5.5), we have:

$$expend_N = P_N c_N + P_S^f c_S^f$$

$$(=) expend_N = P_N \left(\hbar \frac{\bar{P}_N}{P_N} \bar{c}_N \right) + P_S^f \left((1-\hbar) \frac{\bar{P}_N}{P_S^f} \bar{c}_N \right)$$

$$(=) expend_N = \hbar \bar{P}_N \bar{c}_N + (1-\hbar) \bar{P}_N \bar{c}_N$$

$$(=) expend_N = \hbar \bar{P}_N \bar{c}_N + \bar{P}_N \bar{c}_N - \hbar \bar{P}_N \bar{c}_N$$

$$(=) expend_N = \bar{P}_N \bar{c}_N$$

C.2. Aggregate capital and aggregate consumption

Differentiating expressions (5.9) and (5.10) with respect to time, we obtain:

$$\dot{\bar{C}}_N(t) = \mu_N N_N \left(\int_{-\infty}^{t} \dot{\bar{c}}_N(t_0,t) e^{\mu_N(t_0-t)}\, dt_0 - \mu_N \int_{-\infty}^{t} \bar{c}_N(t_0,t) e^{\mu_N(t_0-t)}\, dt_0 \right) + \mu_N N_N \bar{c}_N(t,t) - 0$$

$$(=) \dot{\bar{C}}_N(t) = \mu_N N_N \bar{c}_N(t,t) - \mu_N \bar{C}_N(t) + \mu_N N_N \int_{-\infty}^{t} \dot{\bar{c}}_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0 \qquad (5.41)$$

$$\dot{\mathcal{A}}_N(t) = \mu_N N_N \left(\int_{-\infty}^{t} \dot{a}(t_0,t) e^{\mu_N(t_0-t)}\, dt_0 - \mu_N \int_{-\infty}^{t} a_N(t_0,t) e^{\mu_N(t_0-t)}\, dt_0 \right) + \mu_N N_N a_N(t,t) - 0$$

$$(=) \dot{\mathcal{A}}_N(t) = \mu_N N_N a_N(t,t) - \mu_N \mathcal{A}_N(t) + \mu_N N_N \int_{-\infty}^{t} \dot{a}_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0$$

$$(=) \dot{\mathcal{A}}_N(t) = -\mu_N \mathcal{A}_N(t) + \mu_N N_N \int_{-\infty}^{t} \dot{a}_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0. \qquad (5.42)$$

Using the wealth constraint (5.4) and the equation (5.42) yields:

$$\dot{\mathcal{A}}_N(t) = -\mu_N \mathcal{A}_N(t) + \mu_N N_N \int_{-\infty}^{t} \left[(r_N + \mu_N - \gamma) a_N(t_0,t) + (1-\Gamma) w_N(t) l_N + d_N(t) - \bar{c}_N(t_0,t) \bar{P}_N - p_{H_N} \vartheta h_N \right] e^{-\mu_N(t-t_0)}\, dt_0$$

$$(=)\dot{\mathcal{A}}_N(t) = -\mu_N\mathcal{A}_N(t) + \mu_N N_N \int_{-\infty}^{t} (r_N + \mu_N - \gamma) a_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0$$
$$+ \mu_N N_N \int_{-\infty}^{t} (1-\Gamma) w_N(t) l_N e^{-\mu_N(t-t_0)}\, dt_0 + \mu_N N_N \int_{-\infty}^{t} d_N(t) e^{-\mu_N(t-t_0)}\, dt_0$$
$$- \mu_N N_N \int_{-\infty}^{t} \bar{P}_N \bar{c}_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0 - \mu_N N_N \int_{-\infty}^{t} p_{H_N}(t) \vartheta h_N e^{-\mu_N(t-t_0)}\, dt_0$$

$$(=)\dot{\mathcal{A}}_N(t) = -\mu_N\mathcal{A}_N(t) + (r_N + \mu_N - \gamma)\mu_N N_N \int_{-\infty}^{t} a_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0$$
$$+ (1-\Gamma)\mu_N N_N \int_{-\infty}^{t} w_N(t) l_N e^{-\mu_N(t-t_0)}\, dt_0 + \mu_N N_N \int_{-\infty}^{t} d_N(t) e^{-\mu_N(t-t_0)}\, dt_0$$
$$- \bar{P}_N \mu_N N_N \int_{-\infty}^{t} \bar{c}_N(t_0,t) e^{-\mu_N(t-t_0)}\, dt_0 - \vartheta \mu_N N_N \int_{-\infty}^{t} p_{H_N}(t) h_N e^{-\mu_N(t-t_0)}\, dt_0$$

$$(=)\dot{\mathcal{A}}(t) = -\mu\mathcal{A}(t) + (r_N + \mu - \gamma)\mathcal{A}(t) + (1-\Gamma)W(t) + D(t) - \bar{P}_N \bar{C}_N(t) - p_{H_N}(t)\vartheta H$$

$$(=)\dot{\mathcal{A}}_N(t) = (r_N - \gamma)\mathcal{A}_N(t) + (1-\Gamma)W_N(t) + D_N(t) - \bar{P}_N \bar{C}_N(t) - p_{H_N}(t)\vartheta H_N.$$

The above expression denotes the aggregate law of motion for capital where $W_N(t) = w_N(t) l_N N_N$ is the aggregate wage income, $D_N(t) = d_N(t) N_N$ represents the aggregate dividend payments and $H_N(t) = h_N N_N$ denotes the aggregate health consumption. Rewriting the individual's optimization problem subject to its lifetime budget constraint yields the following optimization problem:

$$\max_{\bar{c}_N(t_0,m)} U = \int_t^{\infty} \left(\frac{\bar{c}_N(t_0,m)^{1-\theta} - 1}{1-\theta} \right) e^{(\rho+\mu_N)(t-m)}\, dm$$

$$s.t.\, a(t_0,t) + \int_t^{\infty} \left[(1-\Gamma) w_N(m) l_N + d_N(m) - p_{H_N}\vartheta h_N\right] e^{-\int_t^m (r_N(n)+\mu_N-\gamma)dn}\, dm = \bar{P}_N \int_t^{\infty} \bar{c}_N(t_0,m) e^{-\int_t^m (r_N(n)+\mu_N-\gamma)dn}\, dm. \tag{5.43}$$

The first order condition (FOC) is

$$\frac{(1-\theta)\bar{c}_N(t_0,m)^{1-\theta-1}(1-\theta)}{(1-\theta)^2} e^{(\rho+\mu_N)(t-m)} - \lambda(t)\bar{P}_N e^{-\int_t^m (r_N(n)+\mu_N-\gamma)dn} = 0$$

$$(=)\bar{c}_N(t_0,m)^{-\theta} e^{(\rho+\mu_N)(t-m)} = \lambda(t)\bar{P}_N e^{-\int_t^m (r_N(n)+\mu_N-\gamma)dn}.$$

In the period $(m = t)$yields:

$$\bar{c}_N(t_0,t)^{-\theta} e^{(\rho+\mu_N)(t-t)} = \lambda(t)\bar{P}_N e^{-\int_t^t (r_N(n)+\mu_N-\gamma)dn}$$

$$(=)\bar{c}_N(t_0,t)^{-\theta} = \lambda(t)\bar{P}_N$$

$$(=)\bar{c}_N(t_0,t) = \left(\frac{1}{\lambda(t)\bar{P}_N}\right)^{\frac{1}{\theta}}$$

$$(=)\lambda(t) = \frac{\bar{c}_N(t_0,t)^{-\theta}}{\bar{P}_N}.$$

And, then, we can write:

$$\bar{c}_N(t_0,m)^{-\theta}e^{(\rho+\mu_N)(t-m)} = \frac{\bar{c}_N(t_0,t)^{-\theta}}{\bar{P}_N}\bar{P}_N e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}$$

$$(=)\bar{c}_N(t_0,t)^{\theta}e^{(\rho+\mu_N)(t-m)} = \bar{c}_N(t_0,m)^{\theta}e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}$$

$$(=)\bar{c}_N(t_0,t)e^{(\rho+\mu_N)(t-m)} = \bar{c}_N(t_0,m)e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}.$$

If we integrate the previous expression, and by using the budget constraint given in the optimization problem (5.43), we have:

$$\int_t^{\infty}\bar{c}_N(t_0,t)e^{(\rho+\mu_N)(t-m)}\,dm = \int_t^{\infty}\bar{c}_N(t_0,m)e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}\,dm$$

$$(=)\int_t^{\infty}\bar{c}_N(t_0,t)e^{(\rho+\mu_N)(t-m)}\,dm = \frac{1}{\bar{P}_N}\left\{a(t_0,t) + \int_t^{\infty}\left[(1-\Gamma)w_N(m)l_N + d_N(m) - p_{H_N}\vartheta h_N\right]e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}\,dm\right\}$$

Additionally, if we consider:

$$\omega_N(t) = \int_t^{\infty}\left[(1-\Gamma)w_N(m)l_N + d_N(m) - p_{H_N}\vartheta h_N\right]e^{-\int_t^m(r_N(n)+\mu_N-\gamma)dn}\,dm,$$

we can rewrite the expression as,

$$\int_t^{\infty}\bar{c}_N(t_0,t)e^{(\rho+\mu_N)(t-m)}\,dm = \frac{1}{\bar{P}_N}\left[a_N(t_0,t) + \omega_N(t)\right]$$

$$(=)\frac{\bar{c}_N(t_0,t)}{\rho+\mu_N}\left[-e^{(\rho+\mu_N)(t-m)}\right]_t^{\infty} = \frac{1}{\bar{P}_N}\left[a(t_0,t) + \omega(t)\right]$$

$$(=)\bar{c}_N(t_0,t) = \frac{1}{\bar{P}_N}(\rho+\mu_N)\left[a_N(t_0,t) + \omega_N(t)\right] \quad (5.44)$$

or, equivalently,

$$\bar{c}_N(t_0,t)\bar{P}_N = (\rho+\mu_N)\left[a_N(t_0,t) + \omega_N(t)\right]$$

$$(=)expend_N(t_0,t) = (\rho+\mu_N)\left[a_N(t_0,t) + \omega_N(t)\right].$$

$\omega_N(t)$ denotes the human wealth of agents which depends on wages lifetime income and dividends net of taxes and private health payments. According to Kuhn and Prettner (2012), the human wealth does not depend on the date of birth because lump-sum dividends are assumed and productivity is supposed to be age independent. Hence, in our case, optimal consumption expenditure in the planning period is proportional to total wealth with a marginal propensity to expend of $(\rho + \mu_N)$. Bearing in mind this and the expression (5.10), it is possible to find an expression for the evolution of the aggregate consumption:

$$\overline{C}_N(t) \equiv \mu_N N_N \int_{-\infty}^{t} \overline{c}_N(t_0, t) e^{\mu_N(t_0 - t)} dt_0$$

$$(=)\overline{C}_N(t) = \mu_N N_N \int_{-\infty}^{t} \left(\frac{(\rho + \mu_N)[a_N(t_0, t) + \omega_N(t)]}{\overline{P}_N} \right) e^{\mu_N(t_0 - t)} dt_0$$

$$(=)\overline{C}_N(t) = \frac{1}{\overline{P}_N}(\rho + \mu_N)\left(\mu_N N_N \int_{-\infty}^{t} a_N(t_0, t) e^{\mu_N(t_0 - t)} dt_0 + \mu_N N_N \int_{-\infty}^{t} \omega_N(t) e^{\mu_N(t_0 - t)} dt_0 \right)$$

$$(=)\overline{C}_N(t) = \frac{1}{\overline{P}_N}(\rho + \mu_N)\big(\mathcal{A}_N(t_0, t) + \Omega_N(t)\big) \tag{5.45}$$

or, equivalently,

$$\overline{C}_N(t)\overline{P}_N = (\rho + \mu_N)\big(\mathcal{A}_N(t_0, t) + \Omega_N(t)\big)$$

$$(=)E_N(t) = (\rho + \mu_N)\big(\mathcal{A}_N(t_0, t) + \Omega_N(t)\big),$$

where $\Omega_N(t)$ denotes the Northern aggregate human wealth. As newborns do not own capital because there are not bequests,

$$\bar{c}_N(t, t) = \frac{1}{\overline{P}_N}(\rho + \mu_N)\omega_N(t) \tag{5.46}$$

$$\overline{C}_N(t, t) = \frac{1}{\overline{P}_N}(\rho + \mu_N)\Omega_N(t) \tag{5.47}$$

holds for each newborn individual and each newborn cohort, respectively. By putting equations (5.6), (5.41), (5.45), (5.46) and (5.47) together, we obtain:

$$\dot{\overline{C}}_N(t) = \mu_N N_N \overline{c}_N(t, t) - \mu_N \overline{C}_N(t) + \mu_N N_N \int_{-\infty}^{t} \dot{\bar{c}}_N(t_0, t) e^{-\mu_N(t - t_0)}\, dt_0$$

$$(=)\dot{\overline{C}}_N(t) = \mu_N N_N \frac{1}{\overline{P}_N}(\rho + \mu_N)\omega_N - \mu_N \left[\frac{1}{\overline{P}_N}(\rho + \mu_N)(\mathcal{A}_N(t_0, t) +)\Omega_N(t) \right]$$

$$+ \mu_N N_N \int_{-\infty}^{t} \frac{1}{\theta} \left(r_N - \gamma - \frac{\dot{\overline{P}}_N}{\overline{P}_N} - \rho \right) \bar{c}_N(t_0, t) e^{-\mu_N(t - t_0)}\, dt_0$$

$$(=)\dot{\overline{C}}_N(t) = \frac{1}{\overline{P}_N}\mu_N(\rho + \mu_N)\Omega_N(t) - \frac{1}{\overline{P}_N}\mu_N(\rho + \mu_N)\mathcal{A}_N(t_0, t) - \frac{1}{\overline{P}_N}\mu_N(\rho + \mu_N)\Omega_N(t)$$

$$+ \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\overline{P}}_N}{\overline{P}_N} - \rho \right) \mu_N N_N \int_{-\infty}^{t} \bar{c}_N(t_0, t) e^{-\mu_N(t - t_0)}\, dt_0$$

$$(=)\dot{\bar{C}}_N(t) = \frac{1}{\bar{P}_N}\mu_N(\rho+\mu_N)\Omega_N(t) - \frac{1}{\bar{P}_N}\mu_N(\rho+\mu_N)\mathcal{A}_N(t_0,t) - \frac{1}{\bar{P}_N}\mu_N(\rho+\mu_N)\Omega_N(t) + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right)\bar{C}_N(t)$$

$$(=)\dot{\bar{C}}_N(t) = -\frac{1}{\bar{P}_N}\mu_N(\rho+\mu_N)\mathcal{A}_N(t_0,t) + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right)\bar{C}_N(t).$$

And then,

$$\frac{\dot{\bar{C}}_N(t)}{\bar{C}_N(t)} = -\mu_N(\rho+\mu_N)\frac{\mathcal{A}_N(t_0,t)}{\bar{C}_N(t)\bar{P}_N} + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right)\frac{\bar{C}_N(t)}{\bar{C}_N(t)}$$

$$(=)\frac{\dot{\bar{C}}_N(t)}{\bar{C}_N(t)} = -\mu_N(\rho+\mu_N)\frac{\mathcal{A}_N(t_0,t)}{\bar{C}_N(t)\bar{P}_N} + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right).$$

As $\bar{C}_N(t) = \frac{1}{\bar{P}_N}(\rho+\mu_N)\big(\mathcal{A}_N(t_0,t) + \Omega_N(t)\big)$,

$$(\rho+\mu_N)\mathcal{A}_N(t_0,t) = \bar{C}_N(t)\bar{P}_N - (\rho+\mu_N)\Omega_N(t)$$

$$(=)(\rho+\mu_N)\mathcal{A}_N(t_0,t) = \bar{C}_N(t)\bar{P}_N - \bar{C}_N(t,t)\bar{P}_N,$$

$$\frac{\dot{\bar{C}}_N(t)}{\bar{C}_N(t)} = -\mu_N\left(\frac{\bar{C}_N(t)\bar{P}_N - \bar{C}_N(t,t)\bar{P}_N}{\bar{C}_N(t)\bar{P}_N}\right) + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right)$$

$$(=)\frac{\dot{\bar{C}}_N(t)}{\bar{C}_N(t)} = -\mu_N\left(\frac{\bar{C}_N(t) - \bar{C}_N(t,t)}{\bar{C}_N(t)}\right) + \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right),$$

rearranging,

$$\frac{\dot{\bar{C}}_N(t)}{\bar{C}_N(t)} = \frac{1}{\theta}\left(r_N - \gamma - \frac{\dot{\bar{P}}_N}{\bar{P}_N} - \rho\right) - \mu_N\left(\frac{\bar{C}_N(t) - \bar{C}_N(t,t)}{\bar{C}_N(t)}\right), \tag{5.48}$$

which is the aggregate Euler equation. This equation is different from the individual Euler equation due to the term $-\mu_N\left(\frac{\bar{C}_N(t)-\bar{C}_N(t,t)}{\bar{C}_N(t)}\right) \in [-\mu_N, 0]$.

Chapter 6

Conclusions

This chapter contains the main conclusions of the thesis and also some proposals for future research.

The most part of the thesis was devoted to the study of the theoretical literature on the IPR impact on economic growth. While in the Chapter 2 a study of theoretical (and empirical) literature about IPR (namely about the effect of IPR on growth/innovation/welfare) was offered, in the Chapter 3 an endogenous growth model was proposed to check the sign of the IPR effect on the growth rate. Moreover, in the Chapter 5, the model developed previously was extended by considering population ageing and health care sector in the formal setting. In this case, we intended not only to verify whether population ageing has some effect on the IPR impact on growth but also to analyse the effect of population ageing on the growth rate. The main goal in these chapters was to understand the IPR effect on growth.

The part of the Chapter 2 related to the theoretical literature on the main topic of research did not allow us to find a clear and prevailing effect of IPR protection on growth. Inversely, we systematized the related literature and showed evidence of all kind of possible results. Another interesting finding was that there were some gaps in this research. We stressed two in particular. First, there is a relative scarcity on studies about the direct effect of IPR protection on economic growth. Studies about the relationship between IPR and economic indicators as innovation, welfare or FDI are more common, and so, the specific relationship we intended to study, demanded to establish a relationship between these economic variables and IPR and, only then, between IPR and growth, which can produce some bias in the analysis. Additionally, it is also more common to find studies about the relationship between IPR-induced factors and growth. Second, the fact that the patent is used in a disproportional way as a measure of IPR enforcement, which may also bring some bias to the gathered results.

Chapter 3 aimed to fill some of the gaps in the research agenda. On the one hand, the model developed in this chapter analysed the direct effect of IPR on economic growth. On the other hand, we defined IPR as a decrease in the probability of imitation because it is common to find that IPR protection becomes imitation more difficult. In this chapter we found a negative relationship between IPR enforcement and the growth rate. This result is not definitive because, as we have referred, there is no consensus about the signal of the IPR effect on growth. However, it is according with those who argue that a strong IPR enforcement is not always suitable to economic growth. Moreover, we can explain the obtained impact, which also constitutes a way in which trade influences negatively the steady state growth rate, by the following: a rise in IPR protection becomes imitation harder in the South (because the imitation cost increases and consequently the probability of imitation diminishes) and there is also a feedback effect which leads to a negative impact on the steady state probability of innovation.

In the Chapter 5, by extending the model developed in the Chapter 3, we found that in a scenario of population ageing, the effect of IPR on growth remains negative although its amplitude can change. Moreover, we concluded that if there is a decrease in the mortality rate, which is synonymous of population ageing, the steady state growth rate increases. This effect on growth happens due to the expansion of the planning horizon of the people (caused by the increase in the longevity) because as they have more time to liquidate the investments, they spend more money to invest in new technologies and less in current consumption. That is, the agents' initial sacrifice is overcompensated by the increase in the lifetime consumption (which is proportionated by the rise in the longevity). Finally, we found that when the increases in labour supply are in the same or higher amplitude than in the health care level, there is, definitely, a positive effect of additional provisions of health care on growth.

The other part of the thesis – the rest of the Chapter 2 and Chapter 4 – was clearly devoted to the empirical literature. The rest of the Chapter 2 revised the empirical literature about the relationship between IPR and growth, while the Chapter 4 tested empirically the model developed in the Chapter 3.

In the part of the Chapter 2 dedicated to empirical literature, we found that several studies observe a positive effect of IPR on economic growth. A possible explanation for this can be the fact that the negative effects of IPR protection are offset by the positive ones. Another possible justification for the predominance of the positive results can be the IPR measure commonly used: patent protection, namely the index of Park and Ginarte (*e.g.*, Xu and Chiang, 2005; Groizard, 2009; Falvey *at* al., 2009). This can create a bias given that this index comprises a sum of different categories of patent rights and it does not allow us to understand the effect of each one on growth. Furthermore, we can also identify a possible, additional bias in the analysis: the sample used. Some of the studies in analysis use only a certain kind of countries or they present estimated results that dependent on the country development level. In line with this, we cannot undoubtedly conclude what is the effect of IPR protection on growth. Therefore, we can add another gap to the two presented about theoretical review: there is an insufficient number of studies about this field of research.

Chapter 4 presented an empirical study, which examines the IPR effect on economic growth. Using a panel dataset of 34 countries in two periods (1997-2011 and 2002-2011) and a two-stage estimation procedure, the analysis showed that IPR protection influences economic growth in robust terms. To avoid some bias created by the IPR measure, we achieved the IPR value residually and then we found that higher levels of IPR protection are associated to lower economic growth rates. Thus, this analysis supports a negative effect of IPR protection on economic growth.

At last, we can state that this work leaves a number of open questions which suggests there is much more work to be done in this research field. Namely, we consider that more research on this specific topic is crucial in order to advance our understanding of the relationship between IPR and economic growth on a worldwide scale, and to be clearly able to go beyond the strict modelling frame. Therefore, for future research, it would be interesting to analyse, for instance, the nature of the sign found by differentiating the expression of the steady state growth rate with respect to IPR parameter (δ) bearing in mind the specificities of each country according to its stage of development. Another possible research is to solve the models for transitional dynamics, using calibration and simulation, in order to understand the behaviour of the main variables along the transition paths. Finally, in our analysis, we verified the effect of IPR, health care and longevity on growth but it would be interesting to study the effect of the growth rate on each one of these variables(the reverse causality) and to test all cases empirically.

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