ESSAYS IN INTERNATIONAL AND INNOVATION ECONOMICS

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Abstract

The first chapter of this dissertation introduces the motivation, explains the system of international patents, and then itemizes the structure of the research. As a non-market route of technology diffusion, international patent transfers account for an important channel of diffusion of new technologies. The aim of the dissertation is to analyze how intellectual property rights (IPR) and product complexity shape this channel of technology diffusion.

In the second chapter, I analyze how firms decide to protect their innovations. Products have different technological complexity, and patenting decisions are made under different IPR enforcement. I simulate the model to characterize the set of patenting firms in terms of their productivity, under different country-industry characteristics. Simulations show a non-monotonicity in the use of patents. I test the model using a subset of patents data from the European Patents Office from 2000 to 2010. The regressions confirm two hypothesis of the model: (i) international transfer of patents and technological complexity have an inverted U shape relation, and (ii) changes in IPR have a larger effect in patenting decisions when industries are located "in the middle" of the spectrum of technological complexity.

The third chapter studies how foreign IPR affects innovation, in the form of productivity improvements, in industries with different levels of technological complexity. I use simple functional forms to derive the endogenous steady state distribution of firms and their innovation growth. I simulate the model to pin down the effects of expanding intellectual property protection. Simulations show a non-monotonicity in the effects of foreign countries strengthening IPR. As technological complexity increases, domestic firms innovate more when foreign IPR increases, and hence the average productivity of these industries increases. However, as complexity approaches to very high complex industries, this effect of stronger foreign IPR dissipates. I test these implications with an industry labor productivity measure from the STAN indicators of the OECD. Estimates support the main findings of the model.

Index words: International Trade, Innovation, Intellectual Property Rights, Technological Complexity, Patents

Dedication

This thesis research is dedicated to the love of my life, my wife Victoria. It would not have been possible without you.

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I am tremendously grateful to Rodney Ludema, chair of my committee, for all his help and patience. I would also like to thank my dissertation committee members Anna Maria Mayda and Lindsay Oldenski for their insightful comments and discussions. Aside from my advisors, I received a lot of support from my classmates Mauricio Tejada, Javier Bustos and Claire Brunel. I would also like to thank my family, who make my life easier and happier.

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Jose Fernandez Donoso

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Chapter 1

Introduction

1.1 International Trade, Technological Complexity and Intellectual Property Rights

How does the interaction between technological complexity and the protection of intellectual property rights (IPR) affect the diffusion of new products and ideas? Even though the set of innovating countries has increased in the last decades, most innovation is still concentrated in rich countries. International trade is one of the channels through which innovation spreads across countries, however it fails to explain why productivity growth is high in countries with very low innovative activity (Eaton and Kortum 1995). Though there is a vast literature on FDI and trade as channels of diffusion (Eaton and Kortum 1996; Archaya and Keller 2009), and the role of IPR protection in facilitating this diffusion (Branstetter, Fisman, and Foley 2006), unfortunately the effect of technological complexity is still unclear.

On one side, more complex products tend to be more knowledge intensive, and hence would benefit greatly from stronger IPR protection (Naghavi, Spies, and Toubal 2011). Indeed, enforceable patents would allow patenting innovative firms to earn markups above marginal cost, as IPR would keep free riding imitators away. On the other hand, more complex technologies are more difficult to imitate, and thus would need less IPR enforcement (Keupp, Beckenbauer, and Gassmann 2009).

In their paper, Keupp et al. (2009) interview managers and executives for U.S. multinational affiliates in different countries. They find that executives in industries of higher technological complexity are less affected by the host country's IPR enforcement, since their product are more difficult to be imitated.

> In general, the government doesn't do a very good job at protection of IPR. However, in the line of chemicals, in the process of chemicals, if the process is relatively complicated, they cannot, you know, its pretty difficult for them to try and copy it. With relatively difficult products, I guess there is a natural barrier [to imitation] . (...) The technology that we put into the market in China is technology that we feel can be somehow uniquely tied up only with our product capabilities, so it's a combination of product and service which cannot be easily replicated. - Case interview Senior R&D Director China (Keupp, Beckenbauer, and Gassmann 2009).

In the last decade, a large amount of economic literature has consistently analyzed how firms seek for protection for their ideas. Recent contributions have assessed how IPR affect international sourcing (Antras 2012; Ponzetto 2009; Branstetter, Fisman, Foley, and Saggi 2007), technological transfers through intra-firm licenses (Branstetter et al. 2006) or firm patenting decisions (Zolas 2011). All these are forms of transferring technology between countries (see next section), which is affected by the potential of imitation and reverse engineering. To my knowledge, no study has deepen the study of technological complexity as an implicit cost on imitation when a new technology is transferred to another country.

This dissertation aims to study two aspects of intellectual property rights and international trade: (i) how do exporting firms protect their new product varieties? and (ii) how is domestic innovation affected by exports? To assess these questions, I emphasize the effect of two factors: the enforcement of intellectual property rights in the importing country, and the technological complexity of the exported goods.

1.2 Patents and International Trade

Patent measures are a common proxy for innovation and technology transfers. In particular, by looking at the relationship between the country where an application (or grant) of a patent was first made, and any subsequent equivalent patent filing in another country indicates that there is a transfer of technology between countries.

To analyze this transfer of new technologies, researchers usually rely on two categories of measures (Maskus, 2000): market-mediated transfers (e.g. trade in goods and services, foreign direct investment, licensing, or migrations among others), and non-market transfers (imitation and reverse engineering, patent applications, or other published information).

If the technology transfer occurs via licensing or FDI, it usually involves the transfer of knowledge, expertise, and equipment to another country. These type of technology transfers generally diffuse widely through other channels (e.g. local employees moving to domestic rival firms taking the knowldge with them), depending on the absorptive capacity of the host country.

Though technology transfers through international trade do not necessarily involve the transfer of other factors (such as equipment), in may cause reverse engineering and imitation in the host country. Trade is a form of transfer where technological innovation is embodied in the product. With accurate information of traded product characteristics, it would be possible to infer the amount of technology transferred between countries. It would not be possible, however, to infer the amount of reverse engineering or imitation.

Nevertheless, specific information of product characteristics is rarely observable in the data, as products improve over time, and these improvements are not captured by available trade data because of the limitations of classification systems. Since firms still have an incentive to protect their intellectual property through patents to avoid the costs of being imitated, patent flows are a useful tool to analyze international technology transfers through trade.

To analyze international technology transfers with patents data, it is essential to understand how international patent flows are registered. This section introduces some basic concepts of how patents work internationally.

1.2.1 What is a patent?

A patent is an exclusive legal right to inventors to exploit their inventions for a limited period of time. Each country has definitions of what is a patentable invention. When a patent is granted, the owner of the patent can exclude other from making, using, or selling the invention without their consent, until the patent expires. Patents give rights to authors only in the country where the patent is granted. If the inventor wishes to gain exclusive legal rights in another country, separate applications must be filed to each country where protection is wanted.

In exchange for the monopoly rights of the invention, the owner agrees to disclose all the details of the invention, and has to pay fees to the patenting authority. Some countries also require that the patent is put to commercial use within a specified period of time.

The monopoly right given by a patent is not automatically enforced. Owners are responsible for looking after their inventions, detecting infringement, and taking legal action if needed.

Not all inventions are patentable, and the set of patentable inventions varies with countries. There are some generalizations applicable to all patent systems. The invention must be new, it must involve an inventive step, it must be useful to industry, and it must not be on the list of excluded inventions .[1]

There are also different types of patents, some of them offered only by a single country. Some countries have different patents for pharmaceuticals, defense, or design. However, most patents are patents of inventions (utility patents in the U.S.).

Since a patent is valid only in the country where it was issued, an inventor seeking protection in several countries must file patent applications for each country separately. In order to help inventors to protect their ideas in multiple jurisdictions, the Paris Convention of Industrial Property was established in 1883. Since then, 169 countries have agreed to sign the Convention. The provisions of the Paris Convention guarantee: national treatment (all patents have the same protection, independent of the nationality of the inventor), right of priority (when an patent is granted in a given country, the invention has priority to be patented in other member countries), and common rules (there are some common rules agreed by all signing countries).[2]

[1] All countries have exclusions, or inventions that cannot be patented. As examples, discoveries, scientific theories, or mathematical methods cannot be patented. The exclusions vary depending on the country.

[2] **Right of priority** means that, after applying for an application in one of the Contracting States, the applicant may, within 12 months, apply for protection in all other Contracting States. Later applications will be regarded as if they had been filed the same day as the first application. With respect to **common rules**, some of the more important are: patents are independent between states (a State granting a patent does not oblige other states to grant that patent), domestic laws in one country cannot be used as grounds to refuse a patent in another country, all States must have patent offices and publish -in an official journal- the names and a brief description of the patents granted, each State is free to legislate as it wishes in industrial property matters.

1.2.2 International patent routes

An inventor seeking protection for its product in multiple countries will need to patent its product in each country separately. However, there are some exceptions. Thirty-one European countries are part of the European Patent Convention (EPC). A patent filed in any of these thirty-one members is valid in all thirty-one members. There are other regional patent organizations, such as the African Regional Industrial Property Organisation, or the African Intellectual Property Organisation.

The purpose of the EPC is to allow inventors to obtain patent protection for their inventions by making a single European patent application. The applicant has to designate the States where he or she wished to gain protection, and pay the fee for each country, all in one single application. When granted, a European patent is a bundle of separate national patents (one for each country designated in the application). Though patent laws in European Contracting States has converged in many aspects, States can legislate their own industrial property laws (in particular with respect to coverage and exceptions).

Additionally, to simplify international filings, there is the Patent Cooperation Treaty, to which 134 countries are party. Though this Treaty simplifies international applications, **there is no such thing as a worldwide patent**. This is important for the purposes of this dissertation, since this explains cross country variations over time in property rights enforcement that can be used to analyze how inventing firms respond to this variation.

1.2.3 Patent families and equivalents

Once the application is filed, it remains confidential between the applicant and the intellectual property office. The application receives a local filing number, or application number, which is given in chronological order. Since the inventor also might want to file patents to other countries, by priority rights provision of the Paris Convention, all filings will be registered with the first application's date, and the first local application number becomes the **priority number**.

The priority data, and the national filing data are reported in the front page when the patent is published. All the applications of the patent filed to other countries are referred to as **equivalents**. In other words, the equivalents are the international filings of a domestic patent. These equivalents are the measure of patent transfers that will be used later on.

1.3 The Structure of the Dissertation

This dissertation studies how international protection of intellectual property rights affect firm international patenting decisions and domestic innovation, with a particular emphasis on product complexity. The remainder of the dissertation is organized as follows. Chapter 2 develops a theoretical model of international patenting decisions, and tests the main results of the model using patents data from PATSTAT. Finally, Chapter 3 uses a dynamic model of innovation to analyze how international patent protection affects the decision to invest in productivity improvements. The empirical test for Chapter 3 uses labor productivity data from the STAN indicators of the OECD.

Chapter 2

Patents, IPR, Complexity, and International Trade

2.1 Introduction

This chapter attempts to investigate how, in an international context, technological complexity may offset effect of different levels of country IPR enforcement on the probability of imitation. I extend the model of international patenting decisions by Zolas (2011), by incorporating three effects of technological complexity: complex products are more sophisticated (higher quality perceived by consumers), are produced at higher marginal cost (need more labor tasks to be produced), and are more difficult to be imitated (fixed cost of imitation for any rival firm). The model is an extension of Ricardian models with monopolistic competition, similar to Bernard, Eaton, Jensen, and Kortum (2003), and de Blas and Russ (2011); with endogenous entry of rivals.

I use a general equilibrium model with monopolistic competition in which a firm exporting an original product variety may be imitated in the host country. If so, firms engage in Bertrand (price) competition. I follow Zolas (2011), where the entry of rival firms is endogenous, and the innovating firm can patent its product variety. Additionally to this framework, I allow industries to have different technological complexities. Complexity affects the product sophistication (similar to product quality models such as Hallak 2006, Hallak and Sivadasan 2009, or Crozet, Head, and Mayer 2009). Technological complexity also plays a role in production, since more complex varieties are produced at higher marginal cost, but also have higher fixed cost of imitation (e.g.

cost of reverse engineering an innovative variety). Finally, since firms use patents to decelerate the endogenous entry of rivals, the decision to patent will also be affected by the extent of technological complexity.

This chapter is organized as follows. Section 2.1 defines the model, solves the algebraic system of equations for an equilibrium, and describes the properties of a numerical simulation of the equilibrium. In section 2.2, I run a series of regressions to estimate some of the implications of the model, using patents data from PATSTAT. Section 2.3 concludes and discusses possible extensions.

2.2 Theory and Equilibrium Properties

2.2.1 The Model

Consider a world with N countries, where each country can produce a continuum of intermediate goods $\omega \in [0,1]$. Intermediate goods are then costlessly assembled by producers of the final good, which will be consumed in the same country where assembled. Three different sources of heterogeneity drive the selection of firms into use of patents: Firms are heterogenous according a random distribution of technological productivity z, intermediate inputs are heterogenous with respect to their complexity ψ, and countries are heterogenous with respect to their protection of IPR, λ, and their level of technology, T.

Complexity

To produce a unit of intermediate input ω, a number of tasks, given by $\psi(\omega) > 1$, must be performed successfully. Because higher $\psi(\omega)$ are associated with a greater number of tasks, I call these technologically complex inputs.[1] Labor is the only factor of production, and the number of labor units to perform each tasks $\psi(\omega)$ is z^{-1}. The amount of labor needed to produce one unit of intermediate input ω is then:

$$L(\omega) = \psi(\omega) z^{-1}$$

and the production technology shows constant marginal costs.

Productive firms (high z) require fewer units of labor to perform all tasks successfully, while firms with lower parameter z will use more units of labor to produce one unit of intermediate input. Hence, if all industries have the same average productivity, more complex industries produce with higher marginal costs.[2]

Consumption

The assembly process by producers of final goods is governed by CES across inputs, with elasticity of substitution $\sigma > 1$:

$$U = \left[\int_0^1 \left(\psi(\omega)^\gamma q(\omega)\right)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}}$$

Each variety ω has some level of technological complexity $\psi(\omega)$, and $\gamma \in (0,1)$ captures preferences for more technologically sophisticated (more complex) products, as in models of firm heterogeneity with product quality (see Hallak 2006, Hallak and Sivadasan 2009, or Crozet et al. 2009). Each variety ω is produced by a single firm

[1]This idea of a larger number of tasks representing more complex goods follows has been used for different contexts: see Keller and Yeaple (2009); or Antras, Garicano, and Rossi-Hansberg (2006).

[2]More complex products can be though and modeled differently: higher fixed (sunk) costs of entry related to RD spending to invent the product variety, higher number of inputs which eventually would translate into higher marginal costs, or tasks in production that are more skill intensive (Keller and Yaple, 2009). For the context of this model (static competition of manufactured goods) the results would not change qualitatively in terms of patents use if instead of increasing marginal costs, product complexity increases fixed costs.

with productivity z drawn from a random distribution $F(z)$. Total expenditure for good ω in country i is given by

$$x_i(\omega) = p_i(\omega) q_i(\omega) = X_i (\psi(\omega))^{\gamma(\sigma-1)} \left(\frac{p_i(\omega)}{P_i} \right)^{1-\sigma}$$

where X_i is the total expenditure in country i, and $P_i \equiv \left(\int_0^1 \left(\frac{p_i(\omega)}{\psi(\omega)^\gamma} \right)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}$ is a CES quality-adjusted price index.

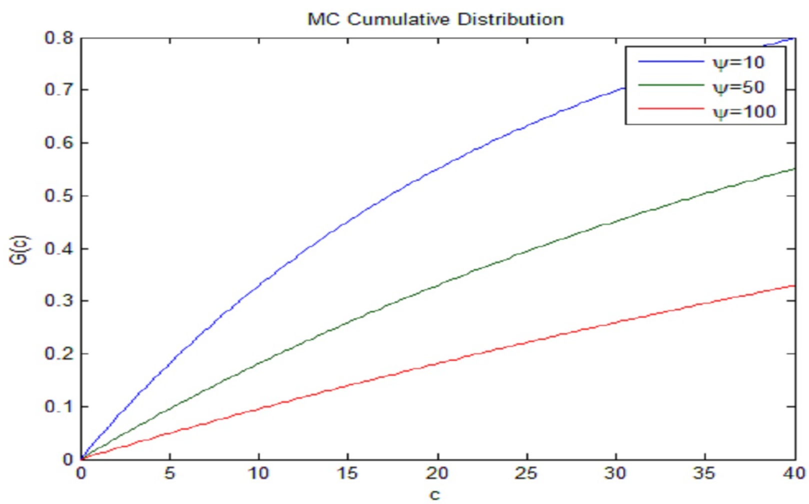
Innovating firms

I follow Melitz (2003), where firms must pay a fixed cost to enter the market and learn their productivity. Once they enter the market, firms must pay a fixed cost to produce. Additionally, exporting firms must pay an entry cost to each foreign market where the product is exported. For firms producing an original variety (or innovating firms), this total fixed cost must be higher than for imitating firms, since innovators must invest in research and development to generate new products. Hence, innovative firms pay a fixed cost of inventing a new product f^e, then learn their productivity to manufacture the new product, and subsequently decide to stay (and produce) or exit the market. Each producing firm pays a fixed cost f_i of production, and a fixed cost f_{ij} to export to each destination country j.

Once an innovative firm pays the entry cost, its corresponding productivity parameter z is drawn randomly. Since there is a fixed cost of learning the productivity, for each product variety only the most efficient firm will end up producing the variety. For simplicity, I assume that the distribution of firm productivity for all product varieties is normalized, and that the random variables of the sequence are independent and identically distributed. Then the limit distribution of the efficiency parameter z must be a distribution of the Generalized Extreme Value functions. I follow Eaton and Kortum (2002), and assume a Fréchet random distribution $F(z)^I$ with support $(0, \infty)$, country parameter of technology T_i, and technology dispersion θ.

To export from country i to country j, exporting firms face iceberg melting trade costs $d_{ij} \geq 1$ with triangle inequality. The marginal cost is $c_{ij}^I(z) = \psi d_{ij} w_i / z$, and follows a Weibull distribution $G_i^I(c) = \Pr(c_{ij} \leq c) = \Pr(z_i \geq \psi_i d_{ij} w_i / c) = 1 - \exp\left[-T_i (\psi w_i d_{ij})^{-\theta} c^{\theta}\right]$.

Figure 2.1: Weibull Distribution of Marginal Cost



As the technological complexity of the product ψ increases, the cumulative distribution of firm's marginal cost shifts downwards. Hence, the expected marginal cost increases as the technological complexity of product varieties increase. Varieties where production requires a high degree of complexity are likely to be performed by firms with high productivity.

To enter each market j, innovating firms must pay a fixed cost of exporting f_{ij}. Unlike innovating firms, rival imitating firms do not pay this fixed entry cost. The monopoly price for the innovating firm with productivity z is:

$$p_{ij} = \overline{m}c_{ij}^{I}(z) = \left(\frac{\sigma}{\sigma-1}\right)\frac{\psi d_{ij}w_i}{z}$$

where $\overline{m} = \sigma/(\sigma-1)$ is the markup over marginal cost, and is equivalent to Melitz (2003) in the absence of rivals.

Imitating Rivals

For each new product ω in each market j, the innovating firm faces r_j rivals. This number of rivals is determined endogenously by the productivity and the complexity parameters. I assume that an imitator is never more efficient at producing ω than the firm who invented it. This assumption follows Zolas (2011) and De Blas and Russ (2011), and it limits the analysis to a smaller set of imitators. To justify the assumption, it may be helpful to think that if an imitator were more efficient than an innovator, the firm would use resources to invent a new variety and gain a full monopolistic markup. Also, the assumption of innovators being more productive than imitators does not necessarily imply lower marginal cost of serving the intermediate input in the market destination. Since innovators face transportation costs and differences in wages, the imitator could still serve the local market at a lower marginal cost than the innovator. The assumption of lower productivity and the Bertrand competition setup imply that the rival firm never gets positive profits unless the innovator exits the market.

I model the complexity of each product (industry) as exogenous, and there is a unique technological complexity to produce each product variety which does not depend on where the product is produced ($\psi_i = \psi_j = \psi$). A rival firm with productivity z_j in market j has a marginal cost $c_j(z) = \psi w_j / z_j$.

Cost of Imitation and Product Complexity

Since imitating requires some cost of learning the technology, each rival firm pays an overhead fixed cost per period, which is positively related to the technological complexity of the product. There are many costs associated to imitation that justify the assumption of a fixed cost of imitating proportional to technological complexity. Additional to a direct cost of imitation (e.g. reverse engineering), products with shorter lifecycle tend to be imitated less often, as the time needed to be successfully imitated generally exceeds the peak of the product cycle (Bilir, 2014). Both evidence and theory indicate that complex products have shorter lifecycles (Marengo and Valente, 2010), hence imitating rivals must deal with higher reverse engineering cost, and a shorter period of time to successfully imitate and market the product (both increasing in technological complexity). For simplicity, I assume that the relation between complexity and the fixed cost of imitation is proportional, and the overhead fixed cost for the imitator is $f_j^R \psi$, where f_j^R.

Entry Decision

If the rival firm decides to imitate the original product variety, after paying an imitation fixed cost $f_j^R \psi$, the firm would learn its productivity z_j. Since the rival cannot be more efficient than the innovator, this productivity follows a Fréchet distribution, truncated on the right by the innovating firm's productivity z_I. The distribution of a rival firm's marginal cost then follows a Weibull distribution, truncated on the left by the innovating firm's marginal cost.[3]

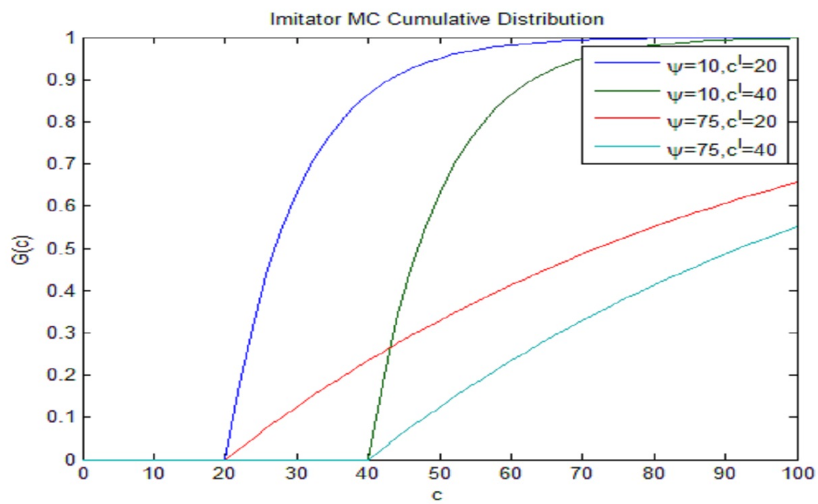
[3]The CDF of the rival's marginal cost function in country j is

$$G_j^R\left(c|c_{ij}^I, T_j, \theta\right) = 1 - e^{-T_j(\psi w_j)^{-\theta}\left(c^\theta - \left(c_{ij}^I\right)^\theta\right)}$$

Left truncated Weibull from Rinne (2009) pp 134-135. CDF for rival's productivity is given by

$$F_j^R\left(z|z^I, T_j, \psi, \theta\right) = e^{-T_j\left(z^{-\theta} - \left(\frac{w_j}{\psi w_i dij}\right)^{-\theta}\left(z^I\right)^{-\theta}\right)}$$

Figure 2.2: Imitator's Truncated Weibull Distribution of Marginal Cost ($d_{ij} = 1, w_i = w_j$)



Hence, the profit function of a rival firm who enters the market and imitates a specific product variety, has the form:

$$\pi_j^R(z) = q_j(z_j)(p_j(z_j) - c_j(z_j)) - f_j^R \psi$$

The price p_j of the variety is determined in equilibrium, depending on the productivities of the innovating and the imitating firms.

If the overhead fixed costs of imitation are non-negative, then there is a productivity cutoff z_j^R for imitators that solves $\pi_j^R\left(z_j^R\right) = 0$. Solving for z_j^R :

$$z_j^R = \left(A \frac{f_j^R \psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}} \frac{\psi w_j}{P_j} \tag{2.1}$$

$$\text{where } A = \frac{\sigma^\sigma}{(\sigma-1)^{\sigma-1}}$$

Rivals with $z_j \geq z_j^R$ stay and compete. Rivals with $z_j < z_j^R$ immediately exit.

The probability of an imitator's successful entry will be determined endogenously in this model, according to the productivity and the technology parameters.[4] Moreover, if the exogenous mass of potential imitators is M_j^R, the number of rivals that an innovator of a given variety faces is also determined by these parameters.[5]

Proposition 2.2.1 *The productivity cutoff for imitating rivals, z_j^R, is increasing in the technological complexity ψ.*

Proof. In Appendix, follows directly from (2.1).

The sophistication parameter γ has no effect on how complexity shifts the productivity cutoff. Indeed, z_j^R is increasing in technological complexity ψ for every product variety ω, and for any degree of product sophistication γ

Proposition 2.2.2 (Zolas 2011) *The number of imitating rivals that an innovator faces, r_{ij}, decreases in the productivity cutoff of imitators, z_j^R. On the other hand, r_{ij}, is increasing in the innovating firm's productivity, z^I.*

Proof. In Appendix

More productive firms face more rivals, and these rivals are more productive on average.

[4]The probability of an imitator's successful entry is:

$$s_{ij}\left(z_j^R|z^I\right) = 1 - F_j^R\left(z_j|z^I, T_j, \theta\right) = 1 - e^{-T_j\left(\left(z_j^R\right)^{-\theta} - \left(\frac{w_j}{w_i dij}\right)^{-\theta}\left(z^I\right)^{-\theta}\right)}$$

[5]The number of rivals that an innovator faces is:

$$r_{ij}\left(z_j^R, z^I\right) = s_{ij} M_j^R = \left(1 - e^{-T_j\left(\left(z_j^R\right)^{-\theta} - \left(\frac{w_j}{w_i dij}\right)^{-\theta}\left(z^I\right)^{-\theta}\right)}\right) M_j^R$$

Corollary 2.2.1 *Innovators producing more technologically complex varieties (higher ψ) face fewer imitating rivals (lower r_{ij}), and these imitators are more productive on average.*

Proof. In Appendix

More productive innovating firms face more rivals, and these rivals are more productive on average. Innovating firms can reduce the number of rivals by increasing the cutoff condition for rival's entry. The implication of these propositions is straightforward. An innovator expects less competition in highly complex industries. In order to decrease the number of effective imitators, firms in these industries do not need as much protection for their ideas as they would in less complex industries.

Competition and markups

Once an innovating firm decides to market a new variety in market j, by Bertrand competition, the only possible competitor is the lowest marginal cost rival. Other rivals' marginal cost will exceed the equilibrium price of the new variety. Note c_{1j} the marginal cost of the lowest marginal cost firm in market j (marginal cost of rival firm with higher productivity). Bertrand competition's equilibrium is such that the price p_{ij} of the variety will equal the minimum between the low-cost rival's marginal cost, and the CES-monopolistic price of the innovating firm is:

$$p_{ij}\left(z\right) = \min\left\{p_{ij}^{B} = c_{1j}, p_{ij}^{M} = \bar{m}c_{ij}^{I}\right\}$$

The innovating firm can charge a markup over marginal cost m_{ij} equal to either the CES-monopolistic markup (if there is no rival entry), or the ratio between the rival's marginal cost and the innovator's.[6] As with the markups, the innovating firm's profits π_{ij}^{I} are also a function of the rival's entry decision.[7]

Since the profit functions, the CDF of the low cost rival, and the CDF of the imitator's markup $h(m_{ij})$ are known, it is also possible to compute the probability of the innovator to charge the CES-monopolistic price. [8]

The probability of the innovating firm charging the monopolistic markup is obtained by integrating $h(m_{ij})$ over values from $\overline{m}$ to ∞:

$$\phi(r_{ij}) = \Pr[m_{ij} \geq \overline{m}] = \int_{\overline{m}}^{\infty} h(m_{ij})\, dm_{ij} = \frac{T_i (w_j)^{\theta}}{r_{ij} T_j (w_i d_{ij})^{\theta} \left(\overline{m}^{\theta} - 1\right) + T_i (w_j)^{\theta}} \quad (2.2)$$

[6] The possible markups of the innovating firm are then:

$$m_{ij}(z) = \min\left\{ m_{ij} = \frac{c_{1j}}{c_{ij}^{I}}, \bar{m} = \frac{\sigma}{\sigma - 1} \right\}$$

[7] The innovative firm's profits are then:

$$\pi_{ij}^{I} = \begin{cases} \pi_{ij}^{B} = q_{ij}^{B}\left(p_{ij}^{B} - c_{ij}^{I}\right) - f_{ij} = X_j \left(\frac{m_{ij} c_{ij}^{I}}{P_j}\right)^{1-\sigma} \left(\frac{m_{ij}-1}{m_{ij}}\right) - f_{ij} & \frac{c_{1j}}{c_{ij}^{I}} \leq \frac{\sigma}{\sigma-1} \\ \pi_{ij}^{M} = q_{ij}^{M}\left(p_{ij}^{M} - c_{ij}^{I}\right) - f_{ij} = X_j \left(\frac{\overline{m} c_{ij}^{I}}{P_j}\right)^{1-\sigma} \left(\frac{\overline{m}-1}{\overline{m}}\right) - f_{ij} & \frac{c_{1j}}{c_{ij}^{I}} > \frac{\sigma}{\sigma-1} \end{cases}$$

[8] The CDF of the low cost imitator is:

$$G_{1j}^{R}\left(c_{1j} | c_{ij}^{I}, r_{ij}, T_j, \psi, \theta\right) = 1 - e^{-r_{ij} T_j (\psi w_j)^{-\theta} \left(c_{ij}^{\theta} - \left(c_{ij}^{I}\right)^{\theta}\right)}$$

The PDF of the markup m_{ij} is:

$$h(m_{ij}) = \begin{cases} \frac{r_{ij} T_i T_j \theta (w_i w_j d_{ij})^{\theta} m_{ij}^{\theta-1}}{\left[r_{ij} T_j (w_i d_{ij})^{\theta} \left(m_{ij}^{\theta} - 1\right) + T_i w_j^{\theta}\right]^2} & \text{for } 1 \leq m_{ij} \leq \overline{m} \\ \int_{\overline{m}}^{\infty} \frac{r_{ij} T_i T_j \theta (w_i w_j d_{ij})^{\theta} m_{ij}^{\theta-1}}{\left[r_{ij} T_j (w_i d_{ij})^{\theta} \left(m_{ij}^{\theta} - 1\right) + T_i w_j^{\theta}\right]^2} dm_{ij} & \text{for } m_{ij} = \overline{m} \\ 0 & \text{for } m_{ij} > \overline{m} \end{cases}$$

with mass point at $\overline{m}$.

Then the expected profit function of the innovating firm is:

$$E\left[\pi_{ij}^{I}\left(z\right)\right]=\phi_{ij}\pi_{ij}^{M}+\left(1-\phi_{ij}\right)E\left[\pi_{ij}^{B}\right]^{9} \tag{2.3}$$

Or, expressed as a function of the markups:

$$m_{ij}^{B}=E\left[m_{ij}|m_{ij}\leq\bar{m}\right]^{10} \tag{2.4}$$

Proposition 2.2.3 (drastic innovation) *The probability that the innovating firm charges the CES-monopolistic markup is increasing with technological complexity of the product variety.*

Proof. In appendix

A drastic innovation is one such that the resulting monopolistic price is lower than the marginal cost of the most productive rival. Therefore, the drastic innovator can preclude any competition and still charge the monopolistic price.

Innovating firms may gain the monopolistic markup only if the monopolistic price is below the marginal cost of the low-cost imitator. With endogenous entry of imitators, the probability that innovating firms generate varieties with characteristics of drastic innovation is higher for more complex industries.

Patenting Decision

In this model, patenting is a mechanism to force competitors to produce around the innovative variety. By paying a fixed cost for patenting, innovating firms generate an

[9] Specifically,
$E\left[\pi_{ij}^{I}\left(z\right)\right]=X_j\psi^{\gamma(\sigma-1)}\left(\frac{\psi w_i d_{ij}}{P_j}\right)^{1-\sigma}\left(z^I\right)^{\sigma-1}\left[\phi_{ij}A+\left(1-\phi_{ij}\right)\left(m_{ij}^{B}\right)^{1-\sigma}\left(\frac{m_{ij}^{B}-1}{m_{ij}^{B}}\right)\right]-f_{ij}$

[10] Specifically,
$m_{ij}^{B}=\int_1^{\overline{m}}m_{ij}h\left(m_{ij}\right)dm_{ij}=\int_1^{\overline{m}}\frac{r_{ij}T_iT_j\theta(w_iw_jd_{ij})^{\theta}m_{ij}^{\theta}}{\left[r_{ij}T_j(w_id_{ij})^{\theta}\left(m_{ij}^{\theta}-1\right)+T_iw_j^{\theta}\right]^2}dm_{ij}$
$=\frac{T_i(w_j)^{\theta}\theta}{r_{ij}T_j(w_id_{ij})^{\theta}(\theta-1)}\begin{pmatrix} {}_2F_1\left(2,\frac{\theta-1}{\theta},\frac{2\theta-1}{\theta},\frac{r_{ij}T_j(w_id_{ij})^{\theta}-T_i(w_j)^{\theta}}{r_{ij}T_j(w_id_{ij})^{\theta}}\right) \\ -\overline{m}^{1-\theta}\left({}_2F_1\left(2,\frac{\theta-1}{\theta},\frac{2\theta-1}{\theta},\frac{r_{ij}T_j(w_id_{ij})^{\theta}-T_i(w_j)^{\theta}}{r_{ij}T_j(w_id_{ij}\overline{m})^{\theta}}\right)\right)\end{pmatrix}$
where ${}_2F_1$ is the hyper-geometric distribution.

additional cost for imitators. The imitator will have to modify the product so that the patent authority does not consider the rival's variety as an imitation. This is, an innovating firm pays a fixed cost f_j^P to patent in country j.

In return for the fixed cost, rivals have to pay an additional overhead fixed cost $f_j^R \psi \lambda$ where $\lambda \in (0, \lambda_{MAX})$ is the level of Intellectual Property Rights enforcement (0 being no enforcement, and λ_{MAX} very high enforcement). Indeed, patents have the duality of giving a monopoly right to the owner in exchange for making public the invention. If there is no enforcement of intellectual property rights ($\lambda \to 0$), the owner of the patent would make its invention public, eliminating any cost of imitation (e.g. no need to reverse engineer). If country j, on the other hand, has intellectual property rights enforcement very high ($\lambda \to \lambda_{MAX}$), the imitating rival will have to spend a lot of resources in modifying the variety so that it complies with industrial property laws (produce around the variety).

To summarize, the innovating firm pays an entry cost f^e and a fixed cost f_i to produce a new product. Once the fixed cost of entry is paid, the firm learns its productivity z, which is drawn from a random distribution. Firms decide to produce or not, depending on the productivity and the fixed cost of production. If the firm decides to produce, he or she chooses the set of countries where the product will be sold. In each destination country j, there will be r_{ij} imitating rivals, depending on the efficiency of the firm, the complexity of the product, and the destination's country technological development. The rival firm with the lowest marginal cost can replicate the product produced by the innovating firm. These rivals exist to ensure that the innovating firm faces a competitive threat, and to smooth the markup of the innovating firm.[11] All agents move simultaneously and the equilibrium will be characterized by a fixed point in all firm's strategies.

After an innovating firm decides to patent, there is a new productivity cutoff $z_{j,pat}^{R}$ for the imitating firm.The new productivity cutoff is:

$$z_{j,pat}^{R} = \left(A \frac{f_j^R \lambda \psi^{1-\gamma(\sigma-1)}}{X_j} \right)^{\frac{1}{\sigma-1}} \frac{\psi w_j}{P_j} \geq z_{j,not}^{R} \tag{2.5}$$

Naturally, the productivity cutoff is increasing in the destination country's IPR enforcement.

Once the innovator holds a patent over his product variety, the potential imitator has to pay a higher fixed cost, which increases z_j^R, and ultimately reduces the number of rivals. The number of rivals when the innovating firm patents its product is now

$$r_{ij,pat} = s_{ij,pat} M_j^R = \left(1 - e^{-T_j \left(\left(z_{j,pat}^R \right)^{-\theta} - \left(\frac{w_j}{w_i d_{ij}} \right)^{-\theta} \left(z^I \right)^{-\theta} \right)} \right) M_j^R \leq r_{ij,not} \tag{2.6}$$

And the innovative firm's expected profits are

$$E\left[\pi_{ij,pat}^{I}(z)\right] = \phi_{ij,pat}\pi_{ij}^{M} + (1-\phi_{ij,pat})\, E\left[\pi_{ij,pat}^{B}\right] - f_{ij} - f_j^P \tag{2.7}$$

An innovating firm will patent if[12]

$$\pi_{ij,pat}^{I}(z,\psi) - \pi_{ij,not}^{I}(z,\psi) \geq f_j^P \tag{2.8}$$

The relationship between ψ and z^P is not monotonic. Moreover, a tractable, closed-form solution of the equilibrium does not exist. I simulate numerically the equilibrium

[11] An alternative way to model imitation is to assume that the innovative firm can either get the entire profit (not imitated) or zero profit (imitated). The setup of this paper seems more realistic, since firms have differences in efficiency. Even if an innovator is imitated, he might charge above marginal cost through the efficiency advantage.

[12] Equivalently, an innovating firm will elect to patent whenever $z_j^I \geq z^P$, and z^P satisfies:

$$\pi_{ij,pat}^{I}\left(z^P,\psi\right) - \pi_{ij,not}^{I}\left(z^P,\psi\right) = f_j^P$$

using a recursive method to solve the system of equations. To do so, I need to define all the exogenous parameters of the model and pin down the wages by adding a tradeable nonmanufactured good (numeraire). Once the wages are defined, I obtain an initial productivity threshold z_{ij}^I for entry into a market. This threshold will yield a nonzero number of rivals, from which the expected markup and the adjusted profits are derived. From the new adjusted profits measure, a new productivity threshold is obtained. I repeat the steps until z_{ij}^I converges. Once z_{ij}^I is defined, I run a similar recursive method with patenting parameters to derive the results incorporating the patenting decision. I use MATLAB to do the numerical process.

2.2.2 Equilibrium Properties

This section calculates a numerical solution using different parameter estimates. To outline the numerical solution to an equilibrium, I use an iterative process that eventually converges on the fixed point of equilibrium. To compute such fixed point, I needs to define all the non-patenting exogenous parameters (T, θ, σ, M, d, ψ, γ, f).

Since a tractable, analytical solution does not exist, I run several simulations with different parameter estimates to predict how firms behave in terms of their patenting decision.

Using similar parameters, Zolas (2011) simulates a model without differences in industry technological complexity. In equilibrium, his model predicts that countries with higher states of technology, more competition, and better patent protection use patents more intensively. I restrict my simulations to analyze the impact of IPR on the patenting decision of products with different technological complexity, when trade happens between countries with different technology levels. I simulate bilateral trade (one exporting, one importing country of a given product variety) to analyze how product complexity and importing country IPR affect the patenting decision of the innovating firm.

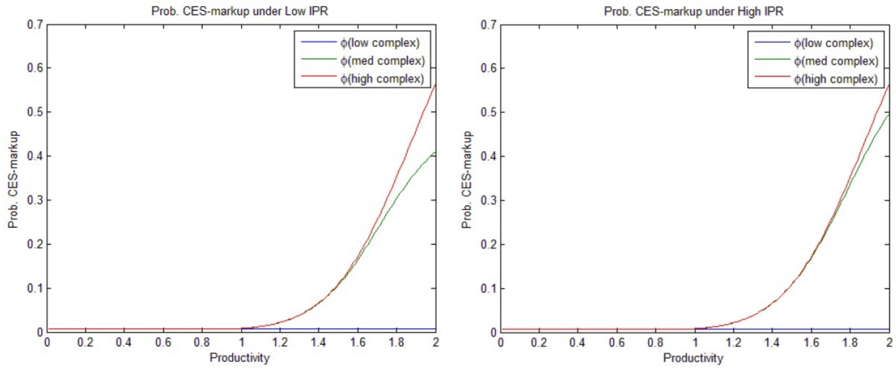
I simulate trade between two countries ($N = 2$). The baseline parameter estimates set symmetry between industries, $\sigma = 5$ and $\theta = 8.28$ as in Bernard et al. (2003) and Eaton and Kortum (2002). I set the number of potential entrants in 20, as in Atkenson and Burstein (2008), and de Blas and Russ (2011). I set the country technology parameter to be one for low-tech countries, and two for technologically developed countries (default in my model). For perfect IPR enforcement, $\lambda_{MAX} = 3$, hence patenting doubles the overhead cost, as used in Zolas (2011), and the intellectual property rights enforcement is either perfect ($\lambda = 2$) or low ($\lambda = 1.07$).

I compute the equilibrium characteristics for $z^I \in (0, 2)$, which, according to the parameters chosen and the distribution functions, includes 99.68% of innovating firms for high-tech countries, and 99.36% for low-tech countries. Industries are characterized in terms of technological complexity as: level 1 for non-complex ($\psi = 1$), level 2 for low ($\psi = 5$), level 3 for medium-low ($\psi = 20$), level 4 for medium ($\psi = 75$), level 5 for medium-high ($\psi = 300$), and level 6 for high ($\psi = 1000$). Parameter estimates for other variables do not matter for the simulations.

Complexity, IPR, and trade between technologically developed countries

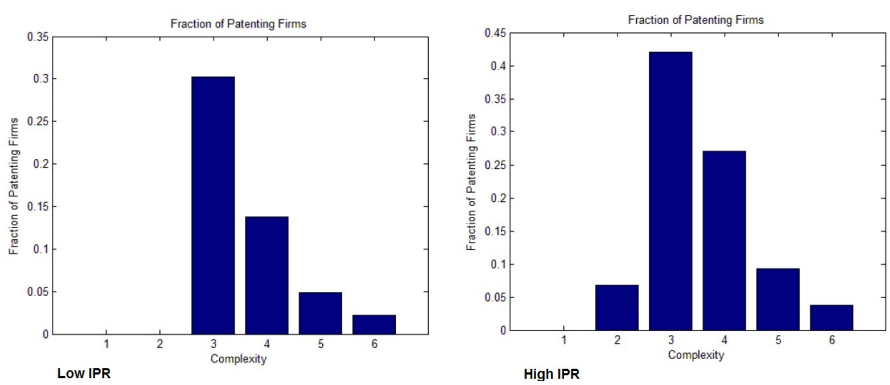
The basic framework assumes that both exporting and importing countries are identical in technology. The figures show simulations under high and low intellectual property rights enforcement for the probability of charging the CES-monopolistic markup (becoming a drastic innovator), the proportion of patenting firms for each technological complexity group, and the expected profits as a function of the firm productivity.

Figure 2.3: High-Tech to High-Tech Trade: Prob. of CES markup for innovators



The simulations are always consistent with Proposition 2.2.3, since the probability of gaining the monopolistic markup is always higher when complexity increases. In high-tech industries, the simulations show that very productive firms may engage in drastic innovations with probabilities as high as 60%. Though the effect of changes in IPR are different, depending on the complexity of each industry. Increasing IPR does not significantly change the probability of gaining the full CES-markup when complexity is very low or very high, but has a significant impact on medium complexity.

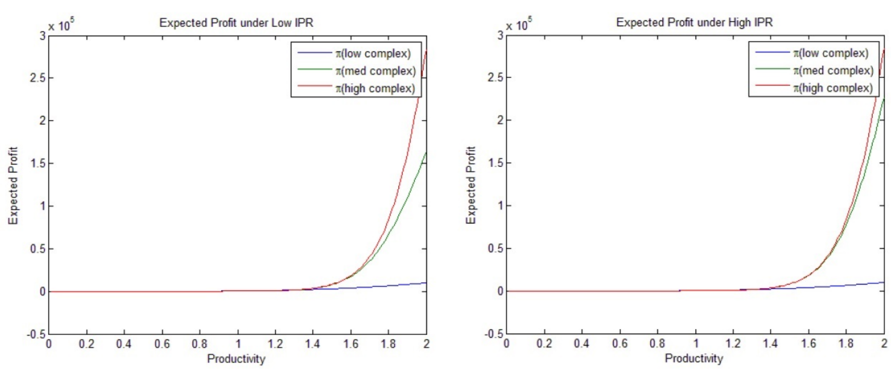
Figure 2.4: High-Tech to High-Tech Trade: % of Patenting Firms



As for the intensity of patenting, the patent applications in highly complex industries when IPR protection is very high is very similar than when the protection is low. Industries showing no complexity in production never use patents in the baseline model, and are unaffected by changes in intellectual property rights. For both low and high IPR enforcement, there is a higher fraction of patenting firms in the middle of the complexity spectrum. Moreover, for high IPR the patenting pattern follows an inverted U-shape, as patenting increases with complexity until level 3, and then decreases.

Industries from low to medium-high technological complexity are the most affected by changes in IPR. If a technologically developed country changes its IPR regime from very low to perfect enforcement, 6.7% of innovating firms in low complexity industries will start using the patent system. In the medium-low complexity group, patenting firms increase from 30.25% to 42%; in the medium group the share grows from 13.7% to 27% of innovating firms; and in the medium-high from 4.9% to 9.3%. The change in high complexity industries is very small, with an increase of less than one percentage point. This change in the pattern of patenting firms confirm the intuition that highly technological complexity generates an additional cost of imitation for competition.

Figure 2.5: High-Tech to High-Tech Trade: Expected Profits for Innovators

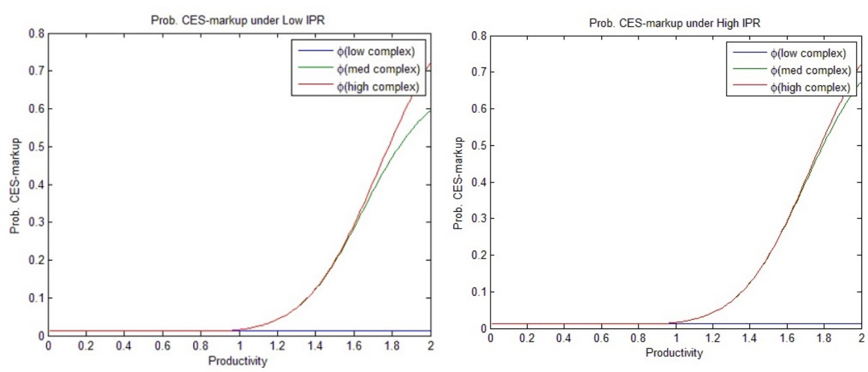


An important result of the simulations is related to expected profits. Under low IPR regimes, low complexity industries will always get lower profits than industries with no complexity. Low patents enforcement generates imitators' entry at a lower cost. When IPR increases, more innovating firms choose to patent their innovation, deterring imitators and increasing the probability of gaining monopolistic markups. This changes the slope of the profits function as the productivity of firms increases, hence gaining higher profits than industries without any technological complexity. IPR clearly benefits the industries "in the middle" of the technological complexity spectrum.

High-tech country exporting to low-tech country

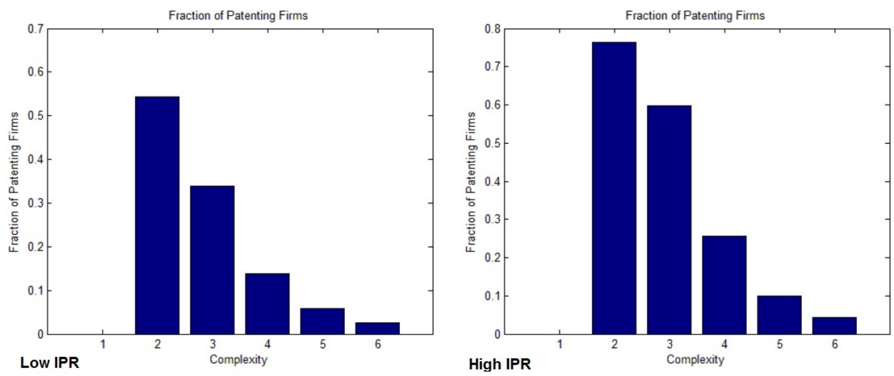
By setting different country technological levels in the Fréchet distribution of productivities, $T = 2$ for the exporting country, and $T = 1$ for the importing country, the effects of changes in the IPR regime show similar patterns than in the symmetric case.

Figure 2.6: High-Tech to Low-Tech Trade: Prob. of CES markup for innovators



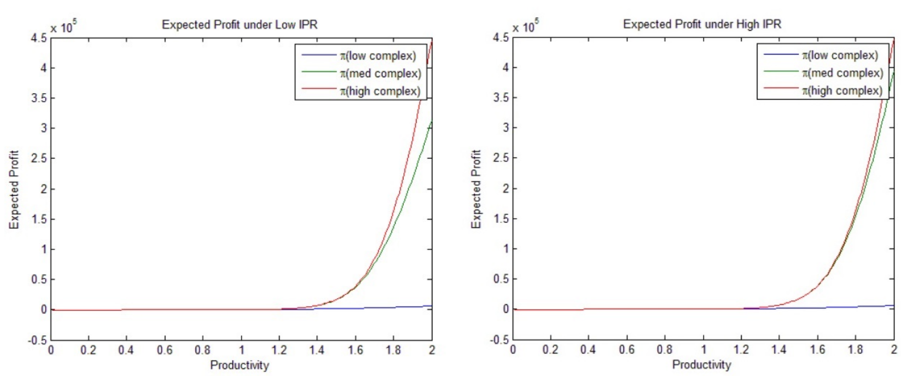
As in the symmetric case, most of the IPR protection effect takes place in industries "in the middle" of the spectrum of complexity. For very high-tech industries, changes in the IPR regime has little effect in the pattern of patenting, increasing only in the margin. For industries without complexity, using the patents system simply does not pay, hence no firm will patent their inventions in equilibrium. Low-complexity, medium-low, medium, and medium-high will change the patterns of patenting. Patenting firms increase from 54% to 76.4% for the low complexity innovators, from 33% to 60% for medium-low innovators, and from 13% to 25% for medium complexity firms.

Figure 2.7: High-Tech to Low-Tech Trade: % of Patenting Firms



The intuition is the following. Since the mass of low-cost imitators is smaller in less technologically developed countries, patenting has a higher impact in the probability of gaining monopolistic markups. Hence, one would expect an intensive use of patents by innovating firms in countries with good enforcement of IPR and low technological development, as long as the technological complexity of the industries of those firms is not too high. For very high-tech industries, the complexity imitation cost is high enough to prevent competition even without using patents.

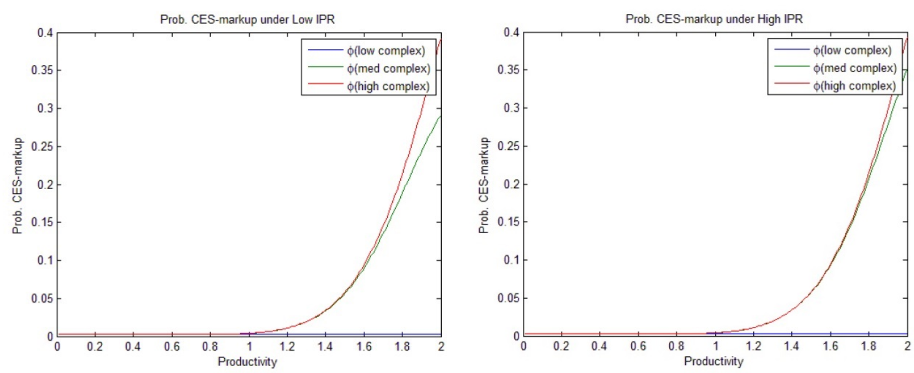
Figure 2.8: High-Tech to Low-Tech Trade: Expected Profits for Innovators



Low-tech country exporting to high-tech country

I now consider the case of firms from a less technologically developed country $(T = 1)$ exporting and facing possible imitators from a technologically developed country $(T = 2)$. This scenario is similar to the national champions' story. National champions has been a strategy of several national innovating systems in middle income and developed countries.

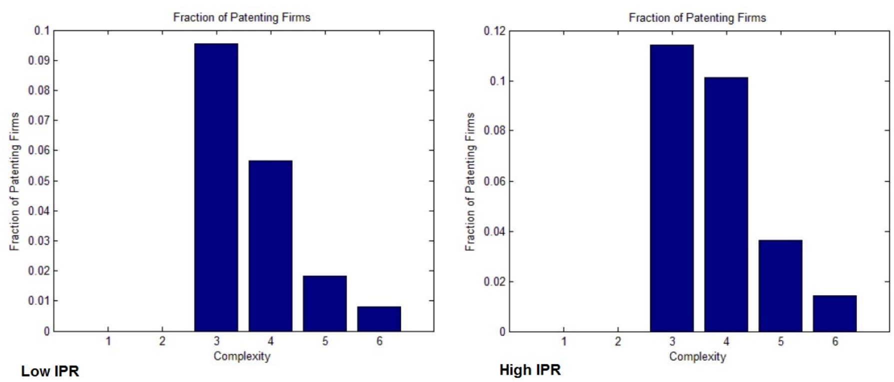
Figure 2.9: Low-Tech to High-Tech Trade: Prob. of CES markup for innovators



The percentage of patenting firms decreases dramatically for any degree of technological complexity, except for the no-complexity (which never patents). While an improvement of IPR protection in the importing country (slightly) increases the set of patenting firms for the medium-low, medium, and medium-high complexity groups, the size of this group is considerably smaller than in the previous context. Moreover, profits of high-tech firms are much lower than the profits of firms in the medium complexity group, or even for the no complexity firms. Only very productive firms gain higher profits, use the patents system, and have probabilities higher than 30% of gaining monopolistic profits.

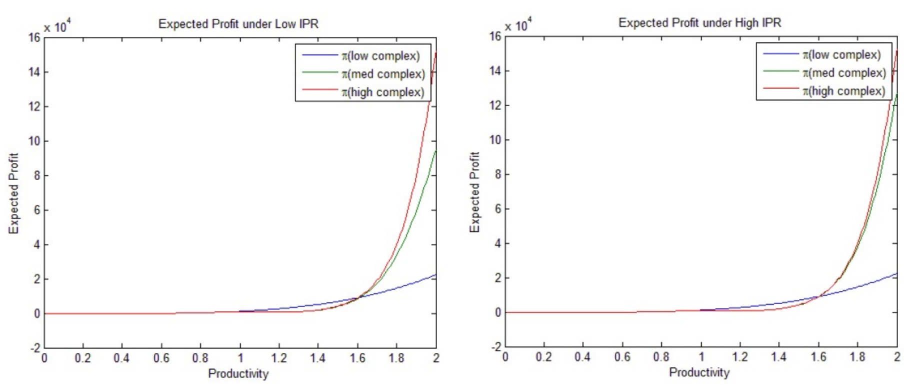
When innovators from countries with lower states of technology export to countries with higher states of technology, patents use is more intensive. The intuition is the following. Innovators face a higher mass of more productive potential imitators in the destination country. Since patents is a mechanism to reduce the probability of being imitated, the use of patents is more intense under this scenario.

Figure 2.10: Low-Tech to High-Tech Trade: % of Patenting Firms



The intuition is the following. The host country has more productive firms on average, and firms in highly complex industries from the exporting country face more low-cost rivals. Only very productive firms will get higher profits than they would if they produced in less technologically complex industries.

Figure 2.11: Low-Tech to High-Tech Trade: Expected Profits for Innovators



The pattern of patents use follows a similar logic. Since the productivity of rivals is higher on average, paying the fixed cost of the patent has little effect on increasing the probability of gaining monopolistic markups. Hence only very productive innovating firms will pay this cost.

2.3 Empirical Analysis

This section tests some of the implications and results of the theoretical model using international patents data. In particular, the model predicts an inverted U-shape relation between complexity and international patents use. Patents use is low in industries with very low or very high complexity, and increases as complexity approaches to some point of the complexity spectrum.

A second implication to be tested is how IPR enforcement changes affect the use of patents. According to the model, IPR enforcement improvements also affects more industries characterized by some degree of technological complexity, but not too complex. In very high or very low complex industries patents are not used intensively, and this intensity is not consistently affected by changes in IPR.

This section is organized as follows. Subsection 2.3.1 describes the data sources and variables construction. Subsection 2.3.2 specifies the empirical strategy for the estimation. Subsection 2.3.3 presents the results.

2.3.1 Data

Patents Data

For bilateral patents flows, I use a subset of the PATSTAT database compiled by the European Patents Office, from 2000 to 2010. The measure of bilateral patent flows are the patent equivalents transferred between country pairs. A patent is transferred from one country to another, if there is an equivalent of the patent filed in the destination country. To measure these transfers, I use PATSTAT database, which publishes the corresponding classification, defined as the Cooperative Patent Classification (CPC), and other characteristics such as the author of the invention, the address (and country of origin), the authority receiving the application, the publication (if applies), or the abstract and citations of the invention.

I use a subset of this data set, which includes all patent transfers between 64 countries. To do so, I use the patent equivalents in other countries to account for patent transfers (see Chapter 1). This subset consists of all patent families, or patents for a single invention applied over multiple jurisdictions. I generate a variable of patent counts, by adding all the patents transferred between two jurisdictions of a specific industry, in a given year. Each observation then represents the number of patents from inventions generated in a country (origin) that are transferred to another country (destination), for every industry in which there is a measurable complexity index.

For the concordance between CPC and ISIC, I use the CPC-IPC-SITC proposition for concordance by Lybbert and Zolas (2012), which uses "Search Terms" in CPC and matched to SITC full description. While this is not a one-to-one concordance system, to my knowledge there is no better linkage between patents and trade data. The concordance at the two digit ISIC to 3 digit CPC is shown in Appendix A.2.

Complexity Data

The measure I use for technological complexity is the product complexity index by Naghavi, Spies, and Toubal (2011), which is similar to Costinot et al. (2011), and Keller and Yeaple (2009). The index uses the U.S. Department of Labor's Occupational Information Network (O*Net), which provides expert information on the importance and the level of complex problem solving for 809 eight digit occupations as defined in the Standard Occupational Classification (SOC). The measures of occupational complexity are then merged to employment information from the

U.S. Bureau of Labor Statistics' Occupational Employment Statistics (OED). The 1999 survey contains the number of employees by occupation and by industry SIC classification (3 digit).

As in Costinot et al. (2011), I assume that all countries have the same production technology for each industry. Hence this measure of complexity is the same for all countries in the sample. The measure of complexity covers 32 industries at the 2-digit SIC codes.

The details to construct this index are explained in the appendix.

IPR Data

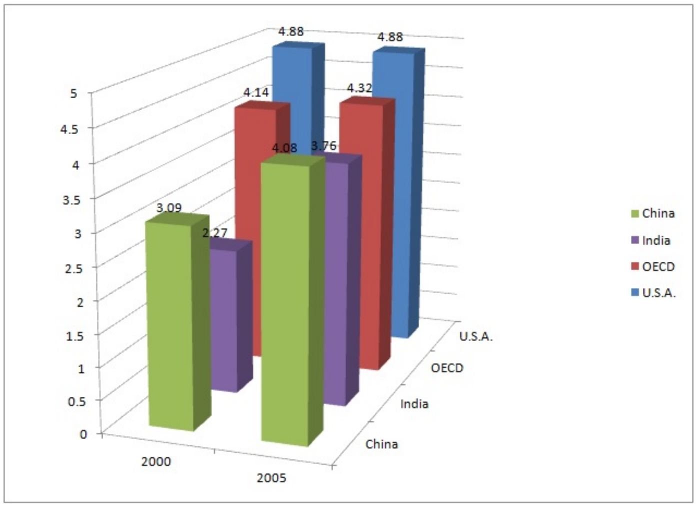
My measure of IPR protection for the destination country is from Park (2008). This measure is an updated version of the frequently used Ginarte and Park index (Ginarte and Park, 1997). The new index incorporates the effects of the TRIPS agreements of 1995 and it takes into account the revisions in the national patent laws required to conform to international and regional agreements.

The index is an unweighted average of five components: (i) coverage, (ii) membership in international treaties, (iii) duration of protection, (iv) enforcement mechanism, and (v) restriction on patent rights. Each component is constructed as a score (0 to 1), so that each country's index of IPR protection goes from 0 (no protection) to 5 (perfect protection).

For the sample, I use the country data for years 2000 and 2005. These numbers are shown in the Appendix. It is worth noticing that many countries did not have significant changes in their IPR scores from 2000 to 2005. Moreover, most significant changes in IPR happened in developing countries.

This means that in the fixed-effects regressions, year fixed effects are identified off only for a subset of developing countries for which IPR has a significant variation.

Figure 2.12: IPR scores (2000-2005) for China, India, OECD, and the U.S.



OECD scores weighted by trade share

Moreover, if most patent transfers happen between developed countries with little variation in their IPR scores, the variation I would be exploiting would be mostly cross-country.

Nevertheless, the total number of patents transferred to the OECD does account for more than 60% of the total amount of patent transfers in the 2000-2010 period. Moreover, the share of patent transfers between OECD member countries accounts for 22.4% of the total amount of transfers between 2000 and 2010. OECD countries are the main generators of patents, but not the exclusive recipients.

Table 2.1: Share of OECD and non-OECD patent transfers from 2000 to 2010

Origin and destination regions	Share of total patent transfers (%, 2000-2010)
OECD to OECD	22.4
OECD to non-OECD	29.3
non-OECD to OECD	39.1
non-OECD to non-OECD	9.2
Total	100

From a total of more than 3 million patent transfers in the sample, non-OECD countries, which account for most of the variance in IPR enforcement, received 38.5% of all patents, which is equivalent to more than 1.1 million patents.

Other Data

For market size and wages, I use GDP and GDP per capita measures from the World Bank Development Indicators. For the country technology parameters T_i, I use the Eaton-Kortum technology parameters obtained by Fieler (2011). For trade costs, I use the great circle distance (in miles) between country capitals. Trade data comes from the Comtrade database by the United Nations.

The summary of the main variables of the regression are presented in Table 2.2 The construction and source of each variable is explained below.

Table 2.2: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Patent transfers	98.94566	1391.205	0	148971
Complexity	.2642735	.0620342	.1146149	.3798102
Industry Exports	6.84e+08	3.17e+09	0	1.17e+11
IPR	4.267105	.4808994	1.28	4.88
Country Tech.	.1410848	.3380422	5.99e-34	1.189953
Distance (miles)	4421.62	2359.687	67	12098
GDP p/c	25340.87	17166.31	311.5502	112028.5
GDP	2.33e+12	3.84e+12	7.74e+08	1.44e+13

Additional data: Patents for Affiliates and FDI

Though foreign direct investment and patenting decisions are beyond the scope of the model, it could also be the case of multinationals using international patents to produce in their affiliates in country j, and then exporting back to country i. To account for this possibility, I include imports (also from Comtrade) as a control. Since my only measure of FDI flows at the industry level comes from the OECD indicators (data only for some OECD members), I ran an additional set of regressions including FDI flows in the appendix.

2.3.2 Empirical Specification

Reduced form equation

I want to test some of the predictions of the theoretical model. In particular, I need to test if the bilateral flow of patents is increasing in technological complexity up to a certain level of complexity, and then decreases (inverted U-shape). Then I want to test if the effect of improvements in the protection of intellectual property has less effect in bilateral patent transfers when these transfers happen in industries with very high or very low technological complexity. Finally, the model predicts a larger transfer of bilateral patents from countries with higher states of technology, and in particular to destination countries with lower states of technology.

To test these predictions, the reduced-form estimating equation is:

$$\begin{aligned} PAT_{ijkt} &= \alpha_t + \alpha_i + \alpha_j + \beta_1 COMPLEX_k + \beta_2 COMPLEX_k^2 \\ &+\beta_3 \left(IPR_{jt} \times COMPLEX_k\right) + \beta_4 \left(IPR_{jt} \times COMPLEX_k^2\right) \\ &+\beta_5 IPR_{jt} + \beta_6 T_i + \beta_7 \left(T_i - T_j\right) + \beta_8 X_{ijkt} + \varepsilon_{ijkt} \end{aligned}$$

Where PAT_{ijkt} is the count of patents of industry k, transferred from country i to country j in yeat t. The variable $COMPLEX_k$ is the technological complexity of industry k, IPR_{jt} is the protection of property rights in destination country j, T_i is the country technology state, and X_{ijkt} is the vector of control variables that includes exports, GDP, and GDP per capita. The theoretical model predicts positive coefficients for β_1, β_3 and β_6. It also predicts negative coefficients for β_2, β_4, and β_7.

Endogeneity concerns

Admittedly, there might be an endogeneity problem with the variables PAT_{ijkt} and IPR_{jt}. A country's patent authority could change its IPR regime as the result of a surge (or drop) in the number of patents transferred to its jurisdiction. This potential interaction might bias β_5. If the receiving country's authority is sensitive to changes in the number of international patent transfers to its jurisdiction, β_5 could be underestimating the effect of IPR on PAT_{ijkt} as the authority could adjust the level of protection according to the number of patents received.

Nevertheless, since my interest lies in the effect of the interacted variables $COMPLEX_k \times IPR_{jt}$ and $COMPLEX_k^2 \times IPR_{jt}$, it is unlikely that the number of patents would affect the sign and significance of these coefficients. The complexity variables $COMPLEX_k$ and $COMPLEX_k^2$ are time and country invariant variables, and IPR_{jt} varies only by destination country and time, the interaction of these variables. Any endogeneity problem between PAT_{ijkt} and IPR_{jt} is likely to affect β_5, but it is not obvious that could bias the signs and signifance of β_3 and β_4.

Pseudo-maximum likelihood estimator

The dependent variable of the model is the count of patents tranferred between country pairs. I follow Santos-Silva and Tenreyro (2006), and use a pseuso-maximum likelihood model, instead of a log linearized gravity model. The intuition is that, since the expected value of the logarithm of a random variable is different from the value of the logarithm of the expectation of the random variable (Jensen's inequality), then the parameters of log-linearized models estimated by OLS are biased under heteroskedasticity. If the model is estimated as a counting outcomes model (Poisson), the estimates are consistent even if the error terms are not distributed Poisson, as long as the errors are robust to heteroskedasticity. I use this particular specification, and check the robustness with a linear model with fixed effects.

The implementation of the PPML estimator is straightforward, as standard statistics programs have commands that permit the estimation of the Poisson regression. This estimator does not take into account heteroskedasticity in the model, which can be solved using Eicker-White (Eicker, 1963; White, 1980) robust covariance matrix estimator.

2.3.3 Results

Testing the complexity story

I first run a series of regressions to test the "inverted U shape" story of complexity and patent use intensity. Table 2.3 shows the full pseudo-maximum likelihood regression, which includes the interacted IPR and complexity coefficients. For the complexity story, the coefficients of interest are complexity and complexity squared. The simulations of the model show an inverted U-shape relation between complexity and the intensity of patents. Once the exports and the IPR controls are introduced, I expect the sign of complexity to be positive, and the sign of complexity square to be negative.

The pseudo-maximum likelihood regression in Table 2.3 shows that, once all the controls are introduced, the signs of complexity and complexity squared are positive and negative respectively, and both are very significant ($p<0.001$).

The same regression is done using a linear specification with year, country (origin and destination) and industry fixed effects. I do not add country fixed effects in some specifications, as Fieler's estimates of countries' technological development do not change in time.

Table 2.3: Patent counts pseudo-maximum likelihood

Patent Counts	PPML 1	PPML 2	PPML 3
Complex	124.906***	85.572***	85.617***
	0.37	0.28	0.28
Complex^2	-272.388***	-181.755***	-181.976***
	0.68	0.52	0.52
IPR*Compl	52.404***	32.655***	32.706***
	0.15	0.11	0.11
IPR*Compl^2	-22.247***	-13.403***	-13.414***
	0.08	0.06	0.06
Exports	0.000***	0.00	0.000***
	0.00	0.00	0.00
Imports	0.000	0.000	0.000
	0.00	0.00	0.00
IPR	3.911***	2.138***	2.139***
	0.01	0.01	0.01
Orig. Tech.		2.235***	2.283***
		0.00	0.00
Tech. Diff.			-0.045***
			0.00
GDP p/c		-0.000***	-0.000***
		0.00	0.00
GDP		0.000***	0.000***
		0.00	0.00
constant	-16.863***	-10.099***	-10.104***
	0.04	0.05	0.04
N	303101	295982	295589
Robust s/e	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

The results are reported in Table 2.4. Both sings and significance are the predicted by the simulations, which confirms the idea of an inverted U-shape relationship between complexity and patent counts.

A simpler version of these regressions is included in the appendix, where I ran a series of regressions (OLS, FE, and PPML) without the IPR-complexity interac-

Table 2.4: Patent counts fixed effects

Patent Counts	FE 1	FE 2	FE 3	FE 4	FE 5
Complex	261.962*	222.406	1596.903*	1563.748*	1571.969*
	125.73	125.59	624.81	636.04	638.15
Complex^2	-2753.82***	-2536.82***	-5062.62***	-5118.35***	-5136.27***
	379.46	379.07	1186.89	1209.63	1213.52
IPR*Compl	693***	618.8***	1208.6***	1193.2***	1197.1***
	87.71	83.65	275.67	281.03	281.88
IPR*Compl^2	-46.228	-35.307	-365.254*	-323.592*	-325.330*
	24.83	24.80	145.05	147.70	148.16
Exports		0.000***	0.000***	0.00	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	-0.000	0.000	-0.000
		0.00	0.00	0.00	0.00
IPR			41.571*	9.571	9.508
			18.51	18.90	18.96
Orig. Tech.				104.972***	101.904***
				1.79	5.35
Tech. Diff.					-3.544
					5.22
GDP p/c				-0.000	-0.000
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
constant	-2.806	-1.056	-179.142*	-92.184	-92.484
	8.85	8.84	79.79	81.33	81.60
N	303101	303101	303101	295982	295589
Robust s/e	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	No	No
Industry FE	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

tion. The signs and significance of the regressors are the expected only when all the controls are included in the specification. The linear specification is sensitive to adding country distance and technology difference between countries. Nevertheless, when running the pseudo-maximum likelihood regression, complexity is positive and very significant ($p<0.001$) in all the specifications. Convexity squared is negative and significant ($p<0.05$) in all specifications as well, and very significant when all the controls are included ($p<0.001$).

It is worth noting that, even without adding IPR, the sign and significance of complexity and complexity squared are the expected. This suggests that, even without controlling for the enforcement of property rights, the relationship between complexity and patents use has the inverted U-shape described previously.

The role of FDI

Though a formal analysis of foreign direct investment goes beyond the scope of the theoretical model, it is still true that it plays an important role in the patenting decisions of multinationals (Branstetter et al., 2006). A multinational with headquarters and R&D facility in country i whishing to produce a variety in an affiliate located in country j, and then export the variety back to country i might transfer the patent of the variety to country j. To control for this effect, I also add the variable imports in the regressions of Tables 2.3 and 2.4. Additionally, I ran an additional set of regressions that also control for FDI flows. None of these variables is statistically significant in the regressions. For FDI flows, the reason could be the source of the data. Since only OECD member countries publish this data in the STAN indicators, I loose many countries in the data. These countries I cannot observe could potentially be the recipients of patents to produce in multinational affiliates, such as India or China.

Robustness check: Patent Applications

If only a subset of patent applications are considered for approval by the authorities, and if that consideration is somehow correlated with the technological complexity of the industry, then the previous regressions are potentially biased. On the other hand, many applications for patents are ineligible because there is no real innovation. Moreover, many applications could be strategic, as firms could try to patent generic ideas in order to deter competition.

Nevertheless, I ran an additional set of regressions considering all the patent applications (granted or not) that are transferred between country pairs. The results are shown in tables A.11, A.12, and A.13. Though the estimates are consistently different with respect to the regressions using patents granted data, the signs and significance of the coefficients show that the story holds, even when using applications' data.

Interpreting magnitudes: Quantile Regression

In addition to fixed effects, and the Poisson Pseudo-Maximum Likelihood specifications, I run a quantile regressions to check the robustness of the other specifications. The quantile regression fits a line at different points of the conditional distribution of the dependent variable (patent counts), given the independent variables (i.e. complexity, IPR, GDP, etc.). This is, the quantile regression fits a line at a given prespecified quantile of the errors distribution.

If complexity was a fully exogenous variable, it would suffice to exclude the variable, split the sample, and run ordinary least squares over each sample. Since complexity is endogenous to the model, splitting the sample could lead to biased estimates (Koenker and Hallock, 2001). I do not include controls for fixed effects, as the regressors are inconsistent for fixed number of periods (time) and can lead to a large bias.[13]

[13] Fixed Effects can be used when using an extremely long panel, longer than the number of quantiles to estimate. Though Powell and Wagner (2011) use a technique for FE with shorter panels in unconditional quantile regressions, their technique is specific to assumptions on the structure of the error that would not apply in this model.

Table 2.5: Unconditional Quantile Regression

Variable	active
q20	
Complexity	2.0825781*
Complexity*IPR	1.618954
IPR	-.0627865
Exports	1.688e-10***
Imports	2.645e-13
Constant	3.3735245***
q40	
Complexity	2.8717074***
Complexity*IPR	2.819673**
IPR	.60052382***
Exports	1.033e-09***
Imports	3.977e-12
Constant	2.7247749***
q60	
Complexity	-10.722723
Complexity*IPR	6.899432***
IPR	1.9306129***
Exports	3.841e-9***
Imports	1.322e-11
Constant	2.431427**
q80	
Complexity	-29.787922*
Complexity*IPR	-12.629445
IPR	9.9071413
Exports	1.841e-08***
Imports	-1.493e-10
Constant	11.349233*
N	303101

* p<0.05, ** p<0.01, *** p<0.001

The results of the unconditional quantile regression are presented in Table 2.5. If a line was drawn at the 20th percentile of the conditional distribution of patent counts, complexity is positive and statistically significant ($p<.05$), and the estimates is 2.08. By increasing the complexity index by one decimal (e.g. from food products and beverages to rubber and plastic products), the number of patents transferred should increase in two decimals on average, other variables constant. When the straight line is drawn at the 40th percentile, this estimate increases to 2.87, and statistically significant. At the 60th percentile, complexity is no longer significant, and it is negative and statistically significant when the line is drawn at the 80th percentile (with estimate -29.78, suggesting a sharp drop in the number of patents for highly complex products).

The quantile regression specification also allows to assess the impact of foreign IPR on patent counts, and the interacted effect of IPR and complexity. Neither IPR nor the interacted coefficient are statistically significant in the 20th or the 80th percentile. This is significant with the prediction of the model of IPR having no effect on products with very low or very high complexity. The effect of IPR is positive and statistically significant for the 40th and the 60th percentile. At the 40th percentile, only IPR accounts for 0.6 patent units per unit increases in the IPR score (e.g. eliminating patent exceptions in the host country). If IPR is interacted with complexity, an additional unit of complexity and IPR would increase the number of patents in 2.8 on average, all other terms constant. This effect is 6.8 patent units if evaluated at the 60th percentile of the conditional distribution. In other terms, if a country where to increase its IPR score by one unit, as complexity the industry complexity also increases above the 60th percentile in one unit, the effect would be almost 7 additional patents transferred to this country.

These magnitudes support the idea of the inverted U-shape, and the result of IPR having a significant effect in industries located around the median of the conditional distribution (or "in the middle of the complexity spectrum").

2.4 Conclusion

The goal of this chapter is to better understand how firms decide whether and where to seek protection for their innovations internationally. These decisions depend on different factors that are difficult to pin down. This paper proposes a new perspective of how firms make this decision, taking into account how technological complexity affects the patenting decision under imperfect competition. The model explains how firms behave in industries with different technological complexity, and in countries with different technological development. It also pins down how intellectual property rights in the destination country affect the decision to patent internationally.

Firms in industries "in the middle" of the technological complexity spectrum are more sensitive to changes in the IPR regime. This pattern of patenting shows a non-monotonocity along the spectrum of technological complexity. Only industries in the middle of the spectrum are sensitive to changes in IPR. Firms in the corners do not respond for different reasons. Very low complexity industries are less likely to charge the monopolistic markup, hence deterring firms from using the patenting system. Firms in industries with high technological complexity are less likely to be imitated, since complexity generates a cost for imitators (e.g. reverse engineering).

The empirical evidence confirms this idea of an inverted U-shape relation between technological complexity and bilateral patent transfers. Moreover, there is evidence that changes in the protection of intellectual property rights do not have substantial effect in the transfer of patents for very high (and very low) complexity industries. International patents data shows that most of the story of better protection boosting the diffusion of innovation happens in industries with some level of technological complexity, since very high complexity is costly to imitate.

A limitation of this chapter is that it does not consider the dynamics of innovation and productivity when there are changes in the protection of intellectual property. Though comparative statics is useful to analyze the idea of complexity shaping the pattern of international patent transfers, it fails to explain productivity changes or innovative effects of IPR in industries with different technological complexity.

Chapter 3

Foreign IPR and Domestic Innovation with Technological Complexity

3.1 Introduction

How does foreign intellectual property rights (IPR) enforcement affect domestic innovation in industries with different technological complexity? Do all firms respond in the same magnitude to the incentives of IPR? Does international protection of intellectual property boost domestic innovation in all exporting industries and firms? This chapter brings up a study of how changes in foreign IPR shape the productivity of domestic firms when products are different in technological complexity.

Current economic literature exhibits evidence in both ways. On one side, some evidence suggests that stronger IPR increases international transactions from multinationals (Javorcik 2002), technology transfer to its affiliates (Branstetter et al. 2006), and both domestic and foreign innovation (Branstetter and Saggi 2009). Moreover, this effect would be stronger in countries with strong imitative ability (Awokuse and Gu, 2010). On the other side, a set of literature claims that there is little or no evidence of significant impact of strengthening IPR on R&D (Ponzetto 2009), or innovation (Qiu 2011). In general, none of these papers control for differences in significant characteristics of products and industries that could impact the cost of imitation.

Indeed, product characteristics that could tie down the imitative ability of local firms in technology receiving countries is a novelty in the study of international economics. Though there is some literature on product complexity and the decision of FDI versus exports (Naghavi, Spies, and Toubal 2011), to my knowledge no paper has focused on the role of IPR in shaping innovation when complexity varies by industry. The focus of this paper is to target that relation: technological complexity shaping the effect of foreign IPR enforcement on domestic innovation. If a productive process uses more complex technologies, innovating firms know that there is an implicit cost of imitation (e.g. reverse engineering, learning the process, adapting technologies, etc.). Moreover, even when the enforcement of IPR is very low in the host country, some firms would keep their strategies with respect to FDI, exports, or technology transfers to affiliates when the production process is very complex (Keupp, Beckenbauer, and Grassman 2009). Hence, one would expect no (or very little) effect of foreign IPR on domestic innovation.

To analyze the effect of international IPR on domestic firms' innovation, I look at the distribution of productivities resulting from a dynamic process of innovation and firm growth, and study how this distribution changes according to international, industry, and firm level forces. Admittedly, many important problems in international trade and industrial organization are intrinsically dynamic: exporting firm growth, innovating behavior, or dynamic responses to policy changes. Dynamic models, however, get complex very fast, and often require a reliance on numerical techniques and examples.

There is a vast literature of international trade with firm heterogeneity that assumes a particular exogenous distribution of productivity (or firm size) among firms. This distribution of productivity comes from a dynamic process with specific assumptions regarding firms. A dynamic model with endogenous firm size distribution has the advantage that the underlying assumptions of firm heterogeneity are known. Firms grow over time because investments are made (e.g. innovations), and die at some point because of exogenous or endogenous reasons. Most models predict a steady state equilibrium of firm growth, and thus an endogenous steady state distribution of firms can be derived. The shape of this distribution depends on the underlying assumptions of firm growth (e.g. capital accumulation, depreciation, innovation, product imitation, patenting), and the parameters of firm exit.

The idea of firm dynamics and steady state distribution was first systematically analyzed by Gibrat (1931). Its findings show a firm size distribution skewed, and following certain regularities accross time and countries. In his paper, he tried to explain this distribution with a model in which a firm's growth each period was proportional to its current size. The intuition for this lies in a virtual set of "opportunities" arising, and the probability of exploiting them would be proportional to a firm's size.[1]

The model I develop is a starting point for exporting firm patenting decisions, when products require different production complexities. It follows Melitz (2003), in the sense that firms pay an overhead fixed cost for exporting, and an additional fixed cost for patenting. As a result, more productive firms become exporters, and the upper

[1]This hypothesis is supported by empirical data on large public firms (Gibrat 1931, Simon 1958). However, more detailed Census data show differences with Gibrat's hypothesis (Evans 1987; Dunnes, Roberts, and Samuelson 1988, 1989): (i) the probability of exit decreases with firm size, and (ii) the rate of growth of a firm conditional on survival is decreasing in firm size. While Gibrat's work does not give the perfect theory since entry, exit, and the mechanisms of growth are not modelled, it still provides a robust mechanism, as regularity of firm's entry and exit suggests. Firm entry and exit are positively correlated accross industries, suggesting differences in sunk costs accross industries, and in the variance of the process that generates these sources of change. Subsequent work on size distribution and dynamics consider the idea of firms acquiring heterogenous managerial talent (Lucas 1978; Garicano and Rossi-Hansberg 2007), and self-selection (Jovanovic 1982). Other related literature include firm growth boundaries (Sutton 1998), power distribution of firm sizes (Stanley et al. 1996; Axtell 2011; Rossi-Hansberg and Wright 2005; Gabaix 2009), industry life cicle models (Jovanic and McDonald 1995), and Schumpeterian growth models (Aghion and Howitt 1992).

tail of the productivity distribution contains the patenting set of firms. Since firms invest in innovation to decrease their marginal cost, over time every firm becomes an exporter, and then patent its product (unless forced to exit prematurely). This setup is particularly useful, as it allows to model the two main dynamic decisions, innovation and patenting, using Bellman's dynamic optimization equation. Another implicit assumption of the model consists of firms not declining in productivity (or size) over time.[2] This assumption implies that patenting firms will renew the patent until expiration.[3] The resulting steady state endogenous distributions can be simulated using numerical tools (such as MATLAB) to analyze the effects of changes in parameters.

In the second part of the chapter, I test the findings of the model using a measure of industry labor productivity collected by the OECD. Since this chapter treats innovation as a productivity improving investment, the proxy for innovation is the growth rate of productivity.[4] The data confirms the intuition that the innovation of domestic firms producing highly complex products will not be affected by changes in international IPR enforcement. Moreover, there is a non-monotonicity in the effect of IPR on innovation and productivity. As complexity increases from no-complexity to some level of technological complexity, the effect of IPR increases. After this level, the effect dissipates as complexity increases, leading to an inverted U-shape.

[2]The simpler version of models where Gibrat's law holds for growth as well as for decline converge to a logarithmic steady state distribution (see Johnson et al., 1992, p.285), and a truncated negative binomial in the generalization case, where small firms grow faster (see Johnson et al., 1992, p.225).

[3]The annual renewal of a patent has two types of benefit: the returns during the coming year and the option to renew it later on. If the patent is not renewed then the assignee loses the rights forever. Pakes (1986) analyzes this dropout of patent holders for France, Germany, and the UK. One of the limitations of the paper is that the cost of renewing is very low. It is implied that non renewals may be due more to product obsolescence (patent turns out to be worth zero) rather than a firm stopping problem.

[4]The first paper of this dissertation defines innovations as new product varieties.

The remainder of this chapter is organized as follows. Section 2 describes the model and simulates the numerical equilibrium. Section 3 contrasts the findings of the model with empirical data. Section 4 concludes.

3.2 Theoretical Background

3.2.1 The Model

The model is based on Melitz (2003). It explores the resulting steady state distribution of exporting firms (in terms of productivity) from a dynamic process with endogenous productive innovation. If exporting firms decide to innovate, they can invest part of their profit to increase their productivity. An innovation is a cost reducing (productivity increasing) technology investment that firms make over time.

This setting is particularly useful to simplify the dynamics of innovation. My final goal is to understand the resulting distribution of firms according to the technological complexity of each industry. This is useful to analyze the effects that different IPR regimes may have on the rate growth of innovation of exporting firms.

Demand

At each instant, firms export intermediate inputs that are costlessly assembled and consumed in an importing country according to CES preferences. Let $\psi(\omega) \in [\psi_{\min}, \psi_{\max}]$ be the complexity of each variety. I normalize the basic complexity level at $\psi_{\min} = 1$. The discounted utility function can be expressed as

$$\begin{aligned} U_j\left(q_{ij}\left(\omega,t\right)\right) &= \int_0^\infty e^{\rho t} Q_j\left(t\right) dt \\ Q_j\left(t\right) &= \left[\int_0^1 \left(\psi\left(\omega\right)^\gamma q_{ij}\left(\omega,t\right)\right)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

where ω is a variety of the intermediate input, $q_{ij}(\omega)$ is the quantity of intermediate goods ω produced in country i and assembled in country j, $\sigma > 1$ is the elasticity of substitution between goods, and γ is a parameter capturing preference for more technologically sophisticated products. Since there are no state variables, the consumer problem can be treated as a static problem, where consumers choose quantity at each instant with a continuum of firms that produce the goods.

Hence, at each instant, consumers solve

$$\max \left[\int_0^1 \left(\psi(\omega)^\gamma q_{ij}(\omega, t)\right)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}}$$

subject to

$$\int_0^1 p(\omega)\, q_{ij}(\omega)\, d\omega = X_j$$

The last line is the budget constraint, and X_j is the total expenditure in country j. The solution for the consumer problem is the quality adjusted Dixit-Stiglitz demand function

$$x_j(\omega) = p_j(\omega)\, q_j(\omega; p, P, X_i) = X_j \left(\frac{p_j(\omega)}{P_j}\right)^{1-\sigma} \tag{3.1}$$

Where P is Dixit-Stiglitz quality adjusted price index

$$P_i = \left[\int_0^1 \left(\frac{p(\omega)}{\psi(\omega)^\gamma}\right)^{1-\sigma} d\omega\right]^{\frac{1}{1-\sigma}} \tag{3.2}$$

Imitation and patenting

Obsolescence and Imitation At any moment, and for each product, there is a pool of potential entrants that can enter by paying an entry cost f_e. Firms die with exogenous probability Δ_{EN}. Firms may exit for two reasons: their product becomes obsolete, or their product is imitated by a competitor in the host market. The probability of firm exit is the summation of these two probabilities (obsolescence and imitation).

As expected, the technological complexity of the product shapes the probability of firm exit. On one side, highly technological (sophisticated) products, that are expected to be more complex on average, become obsolete faster (have a shorter product cycle). Let Δ_D be the probability of product obsolescence, then $\partial\Delta_D/\partial\psi > 0$. On the other side, very complex products are more difficult to imitate (e.g. reverse engineer), and hence have a higher likelihood to survive when there is competition. For simplicity, assume that once a variety is copied in the host country, the firm producing that variety cannot compete and thus exits that market.[5] Let Δ_{IN} be the probability of imitation, then $\partial\Delta_{IN}/\partial\psi < 0$.

Firms then exit the market at any moment with probability Δ_{EN}, where

$$\Delta_{EN} = \begin{cases} \Delta_{IN} + \Delta_D & \text{if} \quad \Delta_{IN} + \Delta_D \leq 1 \\ 1 & \text{otherwise} \end{cases}$$

The final effect of ψ on Δ_{EN} will depend on the functional assumptions on Δ_{IN} and Δ_D.

Patenting Patents are a mechanism to reduce the probability of imitation. For simplicity, I assume that the length of patent protection is forever, and that the vigor of enforcement $\Omega \in [0,1]$ depends on the intellectual property rights of the country where the patent is filed. Firms must pay a patenting cost of f_P units of labor in order to gain protection. Once a product variety is protected by the patenting system, the probability of imitation decreases to the probability of enforcement Ω.

The probability of imitation after a firm decides to patent its product is then $1-\Omega$, and since the intertemporal discount factor is ρ, I can calculate a perpetuity equivalent probability of imitation after patents $\Delta_{IP} = \Delta_{IN} \times \rho\,(1-\Omega)$. The probability of exit

[5] The second chapter of this dissertation develops a detailed model of imitation, where the innovative firm engages in Bertrand competition once a rival imitates its variety.

at any moment for an exporting firm is now Δ_{EP}, where

$$\Delta_{EP} = \begin{cases} \Delta_{IP} + \Delta_D & \text{if} \quad \Delta_{IP} + \Delta_D \leq 1 \\ 1 & \text{otherwise} \end{cases}$$

Productivity and innovation

Firms are owned by the domestic consumers. Given a productivity level z, and labor services n, the firm producing ω has access to the following technology:

$$y\left(\omega; z, n\right) = z^{\frac{1}{\sigma-1}} n$$

There is a preference parameter in the technology, this normalization simplifies the algebra (Atkenson and Burstein 2010). The counterpart is that a change in σ would be hard to interpret, as it would change both the technology and the preferences.

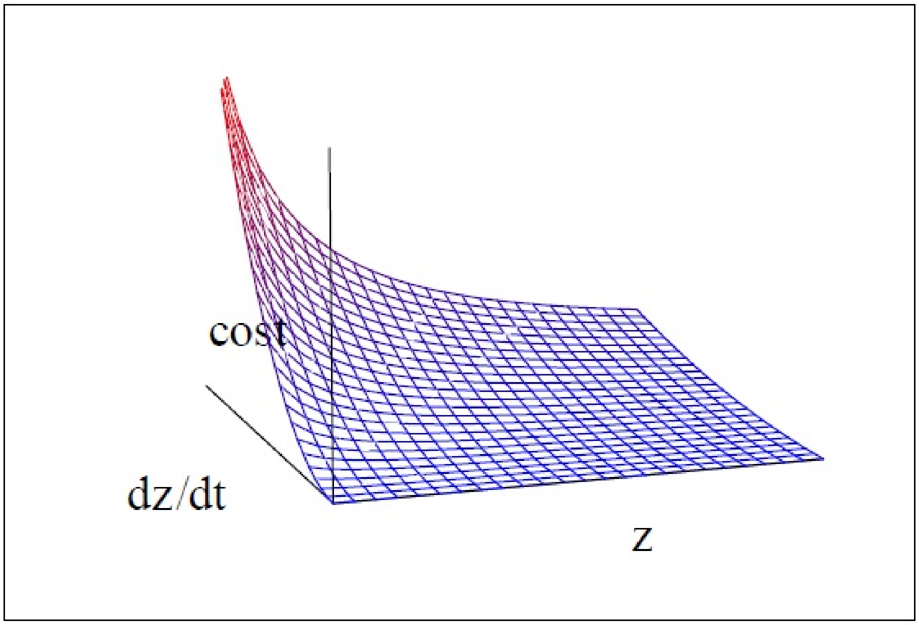
Firms can make expenses to increase their productivity z. The cost in labor units of increasing productivity by amount $\dot{z}$ depends on the current productivity level z, and is given by

$$c_i = \left(z, \dot{z}\right) = \frac{f_{Ii}}{z}\left[\frac{1}{2}\left(\dot{z}\right)^2\right]$$

where f_{Ii} is the cost of innovating in country i, where the innovating firms produce. As firms gain productivity over time, the cost of innovating decreases. This simple form has been widely used in previous papers, as it simplifies the algebra without violating Gibrat's law.

There is a pool of potential exporters that can enter to market j at anytime by paying sunk entry cost f_{xj}. After paying the cost, entrants start producing with productivity $z = 1$. There are iceberg trade costs $d_{ij} \geq 1$ with triangle inequality.

Figure 3.1: Cost of Innovating



3.2.2 The problem of exporting firms

Exporters face two decisions, one static, and two dynamic. The static decision involves how much to produce, and the price to charge for each unit of production. The first dynamic decision is how much to invest in innovation. The second dynamic decision is whether they should patent the product or not.

Static decision

The problem of the firm is deciding how much to produce and the price given its current productivity. If the firm does not patent the product, then the problem is

$$\max_{p,q,n} pq - w_i n$$

subject to

$$q = \frac{z^{\frac{1}{\sigma-1}} n}{d_{ij}}$$

The solution of the problem is the Dixit-Stiglitz markup over marginal cost rule

$$p(\omega) = \frac{\sigma}{\sigma-1} \frac{d_{ij}}{z^{\frac{1}{\sigma-1}}} \tag{3.3}$$

Then the variable profit function (or the profits before paying innovation costs) for a non-patenting firm in each market j is

$$\pi_{Nj}(z, P_j, X_j) = \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \sigma^{-1} X_j P_j^{\sigma-1} z (d_{ij})^{1-\sigma} \tag{3.4}$$

The variable profits in each market j for the patenting firm are the same than non-patenting, with the exception of patenting fixed costs is

$$\pi_{Pj}(z, P_j, X_j) = \pi_{Nj} - f_{Pj} \tag{3.5}$$

I will use these two expressions in the further on for the computation of the dynamic value functions.

Dynamic decisions

Firms have to solve two problems: (i) how much to innovate, and (ii) when to use the patenting system (for the non-patenting firms).

The innovation problem To solve the innovation problem, I have to compute a dynamic system of equations in which patenting and non-patenting firms solve their respective innovation problems.

Innovation problem for the patenting firm The discounted value of the patent as a share of the value function of the firm is already included in Δ_{EP}. This transformation allows for a simpler expression of the discounted value fuction of the patenting firm. Hence the Hamilton-Jacobi-Bellman equation for the patenting firm is

$$(\rho + \Delta_{EPj}) V_{Pj}(z) = \max_{\dot{z}} \pi_{Pj} - w_j \frac{f_{Ii}}{2z} \left(\dot{z}\right)^2 + V'_{Pj}(z) \dot{z}$$

Since z grows over time, every surviving firm will eventually become a patenting firm. I can define a productivity threshold for the patenting decision z_{Pj}. Firms with productivity strictly above z_{Pj} will always patent their product in country j, while firms with productivity $z \in [1, z_{Pj}]$ will not patent.

Innovation problem for the non-patenting firm Since z_{Pj} is the size at which a firm uses the patenting system, then the problem for a non-patenting ($z \in [1, z_{Pj}]$) is

$$\begin{aligned}(\rho + \Delta_{EN}) V_{Nj}(z) &= \max_{\dot{z}} \pi_{Nj} - w_j \frac{f_{Ii}}{2z} \left(\dot{z}\right)^2 + V'_{Nj}(z) \dot{z} \\ & s.t.\end{aligned}$$

$$V'_{Nj}(z_{Pj}) = V'_{Pj}(z_{Pj}) \tag{SP}$$

$$V_{Nj}(z_{Pj}) = V_{Pj}(z_{Pj}) - w_j f_{Pj} \tag{VM}$$

$$V_{Nj}(z = 1) = w_j f_{xj} \tag{FE}$$

The first condition (SP) is the smooth pasting condition. It states that the growth rate of firm size cannot show leaps in the vecinity of $z_{Pj.}$ Moreover, the slope of the value function has to be the same before and after patenting. The second condition (VM), is the value matching condition, which in this case is also the border condition of the problem. The final condition (FE) is the free entry condition. Firms will export to country j until the discounted value of exporting for the exporter with the lowest productivity is equal to the fixed cost of exporting to this country.

Steady state solution of the innovation problem

Patenting firms For the solution of the patenting problem, I define a steady state in which the productivity of patenting firms grows at a constant rate. This is, to solve the patenting firm problem, I guess and verify that $V_P(z)$ is homogenous of degree 1. This implies that the growth rate of firm size is independent of firm size, meaning that Gibrat's law holds.

Solving for the growth rate of the patenting firm

$$g_{Pj} = (\rho + \Delta_{EPj}) \left(1 - \sqrt{1 - \frac{2\pi_{Pj}}{(\rho + \Delta_{EP})^2 f_{Ii}}} \right) \tag{3.6}$$

Then the closed form solution for the value function of the patenting firm is

$$V_{Pj}(z) = w_j f_{Ii} g_{Pj} z \tag{3.7}$$

Non-patenting firms As shown above, the value function for the non-patenting firm ($z \in [1, z_{Pj}]$) is

$$(\rho + \Delta_{EN}) V_{Nj}(z) = \max_{g_N} \left\{ \pi_{Nj} - w_j g_{Nj}^2 z + V_{Nj}^{'}(z) g_{Nj}^2 z \right\}$$

Subject to

$$V_{Nj}(z_{Pj}) = w_j f_{Ii} g_{Pj} z_{Pj} - w_j f_{Pj} \tag{VM}$$

$$V'_{Nj}\left(z_{Pj}\right) = w_j f_{Ii} g_{Pj} \tag{SP}$$

From the first order condition

$$g_{Nj} = \frac{V'_{Nj}\left(z\right)}{w_j f_{Ii}} \tag{3.8}$$

Introducing the solution in the Bellman equation

$$\left(\rho + \Delta_{EN}\right) V_{Nj}\left(z\right) = \left[\pi_{Nj} + \frac{V'_{Nj}\left(z\right)^2}{2 w_j f_{Ii}}\right] z, \forall z \in \left[1, z_{Pj}\right]$$

The equation defines a first order differential equation that pins down the non-patenting firm value function. From the first order condition, I can also pin down the non-patenting firm growth rate of productivity. The border condition is given by the value matching condition, and I can identify the productivity threshold using this condition and the smooth pasting condition. The smooth pasting contidion and equation (8) imply that

$$g_{Pj}\left(z_{Pj}\right) = g_{Nj}\left(z_{Pj}\right) \tag{3.9}$$

Rearranging terms, and normalizing the wage at the exporting country equal to 1, I obtain the differential equation that solves for the non-patenting growth rate

$$V'_{Nj}\left(z\right) = \sqrt{2 f_{Ii}\left(\left(\rho + \Delta_{EN}\right)\frac{V_N\left(z\right)}{z} - \pi_{Nj}\right)} \tag{3.10}$$

With the initial condition $g_{Nj}\left(z_{Pj}\right) = g_{Pj}$, since g_{Pj} does not depend on z.

This differential equation (3.10) cannot be solved in closed form. I compute a numerical solution to the equation with Matlab function *ode45* in the simulations section.

Patenting decision problem The setup of the model is such that firms increase their productivity z over time until they exit. Thus every firm will use the patenting system in country j at some moment in time, unless forced to exit before reaching the productivity threshold z_{Pj}.

To compute the value of z_{Pj}, I use the innovation growth rate property at the patenting size, which states that the firm growth rate shows no leaps before and after patenting. Hence, I plug equation (3.10) in the value matching condition and compute

$$z_{Pj} = \frac{2f_{Ii}\left(g_{Pj}-1\right)\left(\rho+\Delta_{EN}\right)wj}{2\pi_{Nj}+f_{Ii}\left(g_{Pj}\right)^{2}w_{j}} \tag{3.11}$$

The relationship between this productivity threshold and the technological complexity of the industry does not have a unique direction, since Δ_{EN} is not monotonous on ψ. I discuss the results under different parameters in the simulations section.

3.2.3 Steady State Distribution of Firms

Let M be the mass of exporters of a given product (industry). Then, for non-patenting firms, the distribution of productivity is given by:

$$\Delta_{EN}\mu\left(z\right) = -\mu'\left(z\right)g_{N}\left(z\right)z$$

And for patenting firms by:

$$\Delta_{EP}\mu\left(z\right) = -\mu'\left(z\right)g_{P}\left(z\right)z$$

Then for each group of firms, the differential equation has the form:

$$-\frac{\mu'\left(z\right)}{\mu\left(z\right)} = \frac{\Delta}{g\left(z\right)z}$$

Integrating on both sides and taking logs:

$$\log\left(\mu\left(z\right)\right) = \log\left(z^{-\Delta/g(z)}\right)+C$$

Where C is the constant of integration, determined by the border condition. Taking exponentials yields the distribution for each group of exporters.

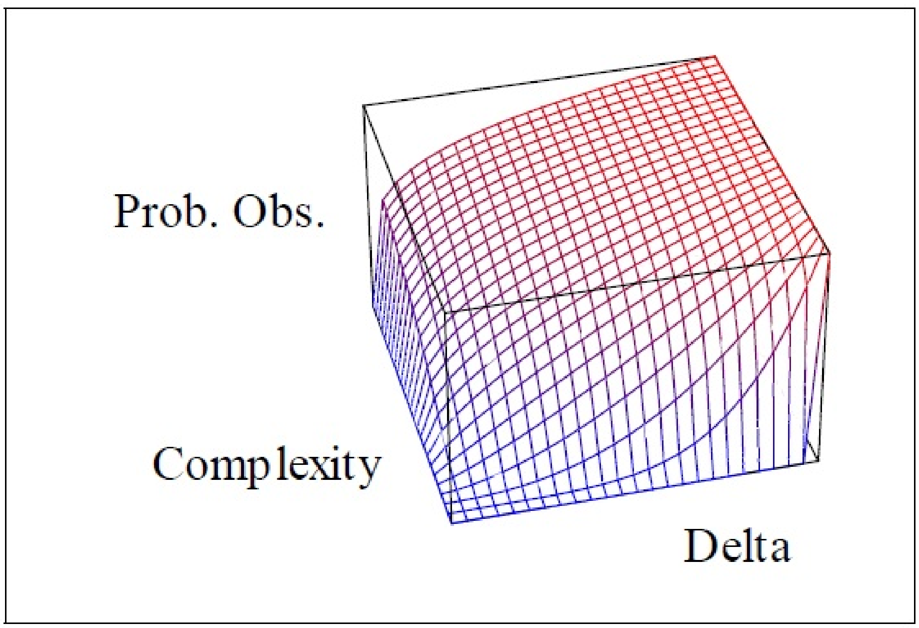
3.2.4 Simulations

Calibration

This subsection simulates the theoretical model. Since most of the results lie in the probability of firm exit, I first need to assume some functional forms for Δ_{IN} and Δ_D.

I assume that $\Delta_D = \delta^{1/\psi}$, where $\delta \in [0, 1]$ is an common probability of firm death. For simulations, I set $\delta = 0.3$.

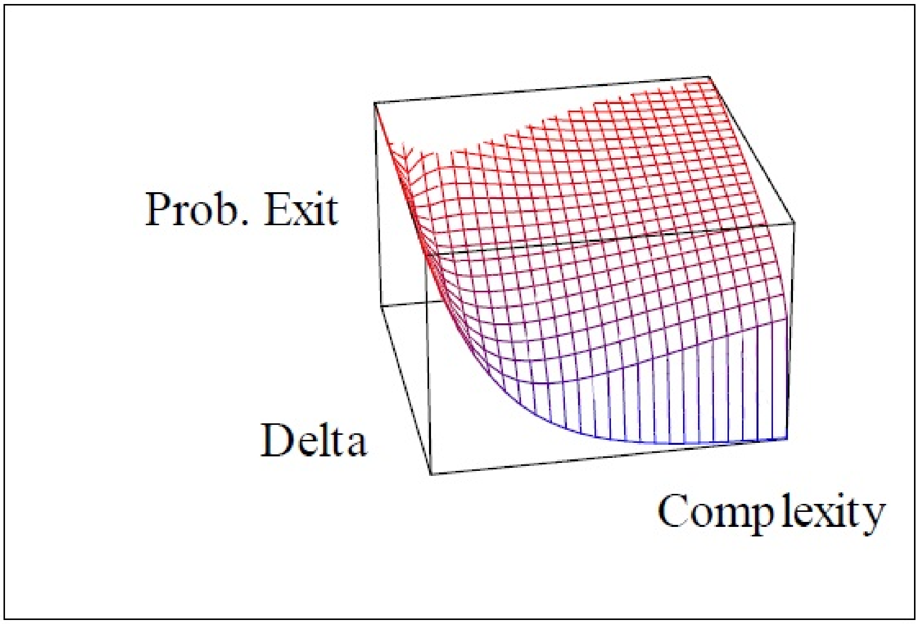
Figure 3.2: Probability of Obsolescence



For the probability of imitation, I assume that complexity increases the cost of imitation exponentially. The probability of imitation is then $\Delta_{IN} = exp(-\psi)$.

To calibrate the simulations, I set $\sigma = 5$ as in Bernard et al. (2003) and Eaton and Kortum (2002). The cost of patenting triples the unit cost of innovation. The discount factor ρ is 4%, and I set the IPR parameters such that Ω is low ($\Omega = 0.102$), medium ($\Omega = 0.226$), or high ($\Omega = 0.406$).

Figure 3.3: Probability of Firm Exit



I also change the technological complexity parameter, so that a product can be of very low complexity ($\psi = 1$), low complexity ($\psi = 1.3$), medium complexity ($\psi = 1.7$), high complexity ($\psi = 2$), or very high complexity ($\psi = 5$).

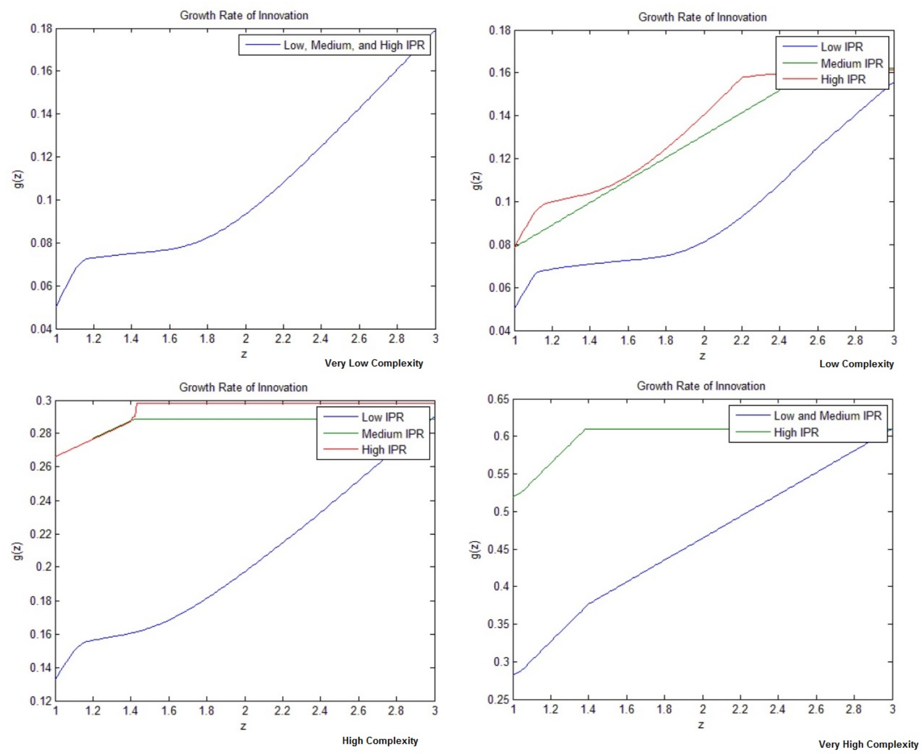
Next, I generate a productivity grid with productivity parameter z in the $[1, 3]$ interval, which means that, under the parameters chosen, the steady state distribution represents between 70% and 95% of the mass of firms. Other parameters do not matter for the simulations.

Firm growth and innovation

This first set of simulations illustrate how changes in the foreign country's IPR enforcement affects domestic innovation depending on the complexity of the product.

Figure 3.4 summarizes the results of the simulations. Each simulation graph is also individually graphed in Appendix B.1.

Figure 3.4: Firm growth and innovation



When technological complexity is very low (Figure B.1), the growth rate of innovation increases as the productivity of the firm gets higher (for productivities from 1 to 3). The steady state at which the growth rate is constant is not achieved in this interval. The path of productivity growth rate is not affected by foreign IPR. Improvements in the enforcement of IPR by trading partners would not change firms' growth rate of innovation.

If the technological complexity increases from very low to low (Figure B.2), the innovation strategy changes when foreign IPR increases. Though the growth rate of firm productivity is non-decreasing with respect to firm size, firms start patenting (curve becomes horizontal straight line) at size 2.4 for Medium foreign IPR, and size 2.3 for High foreign IPR. This suggests that, as foreign IPR increases, firms have incentives to use the foreign patenting system earlier, which changes all the innovation path (from size 1). For Low IPR enforcement, the steady state is not achieved in the [1,3] interval, and the shape of the curve is very similar to the very low complexity case.

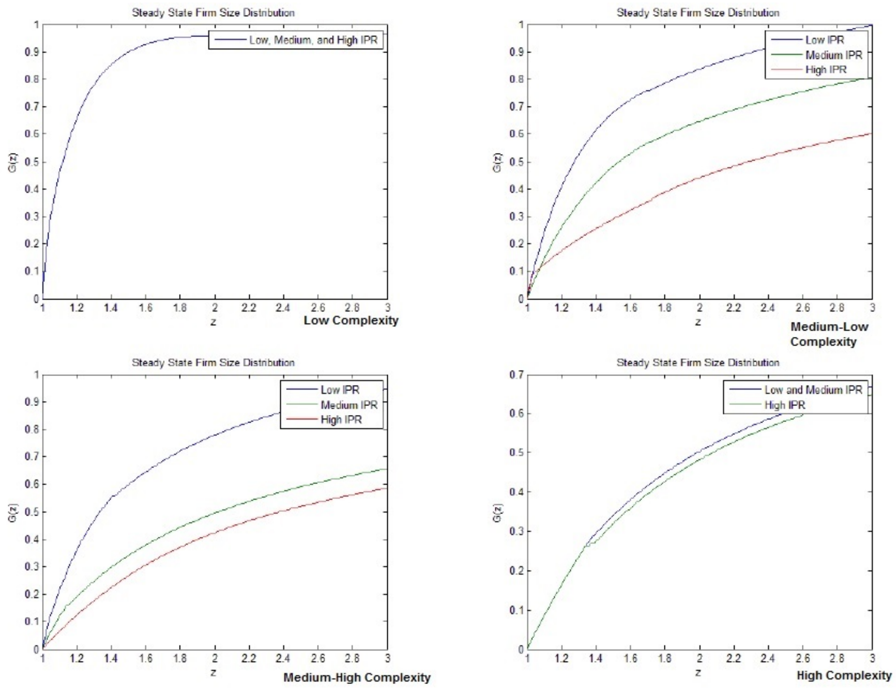
In industries of medium and high technological complexity (Figures B.3 and B.4), firms innovate more. Since the probability of obsolescence is higher, and the demand values the technological sophistication of the product, firms invest more in becoming more productive than in industries with lower technological complexity. As foreign IPR enforcement increases from Low to Medium, more firms use the patenting system (firms of size 1.5 or higher patent their product for medium complexity, and 1.4 or higher for high complexity), and the steady state growth rate of the upper tail of the distribution of firms is almost 30% when foreign IPR and technological complexity are both high.

When technological complexity is very high (Figure B.5), foreign IPR has an effect on innovation only when the enforcement if high. When foreign IPR increases from Low to Medium, there is no noticeable effect on innovation. Since complexity also acts as an implicit cost of imitation, in technologically complex industries patents are less attractive, unless the IPR enforcement is High. In technologically complex industries, simulations show a productivity growth rate above 60% after patenting.

Firm size distributions

The responsiveness of firms to innovation also shapes the steady state distribution of firm productivity (and size). Appendix B.2. shows the effect of IPR on the endogenous distribution of productivities for different technological complexities.

Figure 3.5: Simulations of Steady State Firm Size Distributions



Since I can compute a numerical expression of the distribution of firm productivities, I can also simulate how this distribution changes when foreign IPR increases. For the case of very low complexity (Figure B.6), the steady state distribution of firm size remains unaffected by changes in IPR. This result is expected, since it does not change the growth rate of innovation not the patenting decision (Figure B.1).

As the technological complexity of industries increases to medium complexity (Figure B.7 and B.8), the effect of IPR on the distribution of firm productivity increases. When foreign IPR enforcement increases, the c.d.f. of firm size shifts to the right, indicating a higher mass of more productive firms. This shift is consistent with the previous results of firms innovating more as foreign IPR increases.

For high and very high complexity industries this result no longer holds (Figures B.9 and B.10). When complexity is high, the shift of the cdf is smaller when IPR increases from Medium to High. Moreover, for very high complexity industries, there is no appreciable shift when IPR increases from Low to Medium, and a very small shift when foreign IPR increases from Medium to High. It is also worth noticing that more than 55% of firms have productivities of 2 or more when industries are very complex (compared to less than 5% for very low complexity).

3.3 Empirical Analysis

This section tests some of the implications and results of the theoretical model. The simulations of the theoretical model show that the shifts in the distributions of productivities are larger when the technological complexity is neither too high, nor too low. I test the idea that the relationship between changes on domestic firm innovation and foreing IPR enforcement follows an inverted U-shape form, which depends on the technological complexity of the industry. This is, as the foreign country increases its IPR enforcement, the response in innovation by domestic firms increases as technological complexity increases from no complexity to some level, and then decreases as the complexity becomes larger. In order to test this, I use the labor productivity by industry index collected by the OECD, and check how this index changes when the IPR regime of trading partners changes, depending on the technological complexity of each industry.

3.3.1 Data

The data I collected to test the results of the steady state simulations come from very similar sources than the data of chapter two, except for data on industry productivity.

Since I want to test the effect of foreign IPR on domestic productivity growth, I use industry measured of labor productivity instead of patents data (as in Chapter 2). The construction and source of each variable is explained below.

Complexity Data

The measure I use for technological complexity is the product complexity index by Naghavi, Spies, and Toubal (2011), which is similar to Costinot et al. (2011), and Keller and Yeaple (2009). The index uses the U.S. Department of Labor's Occupational Information Network (O*Net), which provides expert information on the importance and the level of complex problem solving for 809 eight digit occupations as defined in the Standard Occupational Classification (SOC). The measures of occupational complexity are then merged to employment information from the U.S. Bureau of Labor Statistics' Occupational Employment Statistics (OED). The 1999 survey contains the number of employees by occupation and by industry SIC classification (3 digit). The details to construct this index are explained in Appendix A.

As in Costinot et al. (2011), I assume that all countries have the same production technology for each industry. Hence this measure of complexity is the same for all countries in the sample. The measure of complexity covers 32 industries at the 2-digit SIC codes.

IPR Data

My measure of IPR protection for the destination country is a by trading partner weighted average of IPR enforcement from Park (2008). To avoid potential endogeneity problems (IPR changing changing with exports associated with productivity growths), I use fixed weights to generate the foreign IPR measure. Hence, the international protection of intellectual property rights $IPR_{i\omega t}$ that country i faces for industry ω is:

$$IPR_{i\omega t} = \sum_j \frac{q\left(\omega\right)_{ij} IPR_{jt}}{\sum_j q\left(\omega\right)_{ij}}$$

Where $q\left(\omega\right)_{ij}$ is the exports of good ω from country i to country j in 2000, and IPR_{jt} is the Park (2008) IPR enforcement index. The Park (2008) index is an updated version of the frequently used Ginarte and Park index (Ginarte and Park, 1997). The new index incorporates the effects of the TRIPS agreements of 1995 and it takes into account the revisions in the national patent laws required to conform to international and regional agreements.The details of the index are aplained in Appendix B. For the sample, I use the country data for years 2000 and 2005.

Other Data

My labor productivity measure comes from the STAN database, collected by the OECD. In particular, I use the index of labor productivity based on value added and employment data from STAN Database for structural analysis. The construction of this variable is the ratio of value added over total employment. Although hours worked would be preferable as a measure of labor input, at the present time consistent hours worked data at the industry level and for all OECD countries are not available. I exploit the country and time variance for each industry, illustrated in graphs at Appendix B.3.

For market size and wages, I use GDP and GDP per capita, and education spending (as percentage of GDP) measures from the World Bank. To control for country technological development, I use the Eaton-Kortum technology parameters obtained by Fieler (2011). For exports, I use the trade database Comtrade by the United Nations.

The summary of the main variables of the regression are presented in Table 3.1.

Table 3.1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Labor Productivity	.0053248	.2011273	-5.198525	.8063557
Complexity	.2642735	.0620342	.1146149	.3798102
Industry Exports	6.84e+08	3.17e+09	0	1.17e+11
IPR	4.271314	.5201331	1.28	4.89
Country Tech.	.1410848	.3380422	5.99e-34	1.189953
Education	5.356696	1.151121	2.58992	8.73995
GDP p/c	25340.87	17166.31	311.5502	112028.5
GDP	2.33e+12	3.84e+12	7.74e+08	1.44e+13

3.3.2 Estimation Strategy

In order to test the implications of the model, I need a variable that captures the effect on productivity of changes in international IPR for industries with different technological complexity. To do so, I generate an interacted variable ($COMPLEXITY * IPR$) and ($COMPLEXITY^2 * IPR$) . The reduced form specification is given by the equation:

$$\begin{aligned} \frac{z_{i\omega t} - z_{i\omega(t-1)}}{z_{i\omega(t-1)}} &= \alpha + \beta_1 \left(IPR_{i\omega t} * Complex_\omega\right) + \beta_2 \left(IPR_{i\omega t} * Complex_\omega^2\right) \\ &\quad + \beta_3 Exports_{i\omega t} + \beta_5 X_{it} + \delta_t + \eta_i + \varepsilon_{i\omega t} \end{aligned} \tag{3.12}$$

Where $X_{i\omega t}$ is a set of country controls such as education, technological development, GDP, and GDP per capita, and δ_t and η_i are time and country fixed effects. If the complexity story holds, then the coefficients β_1 and β_2 should be positive and negative respectivelly, and statistically significant.

3.3.3 Results

I run equation (3.12) several times, adding different controls. For each set of regressions, I am interest in the sign and significance of the interacted coefficients IPR*Complexity and IPR*Complexity^2. The first coefficient positive and the latter negative indicate a higher effect of foreign IPR on domestic productivity growth for industries in the middle of the complexity spectrum (inverted U-shape), which is the main result of the theoretical model and the simulations.

Table 3.2: OLS, Productivity Growth Rate

	(1)	(2)	(3)	(4)	(5)
IPR*Complexity	0.121**	0.112**	0.113**	0.115**	0.131**
	0.05	0.05	0.05	0.05	0.05
IPR*Complexity^2	-0.276**	-0.256**	-0.258**	-0.268**	-0.301**
	0.10	0.10	0.10	0.10	0.10
IPR	0.1221	0.1299	0.1291	0.1295	0.1556
	0.14	0.14	0.14	0.14	0.14
log(Exports)		0.001**	0.001**	0.001**	0.002**
		0.00	0.00	0.00	0.00
Country technology			0.003	0.013	0.020*
			0.01	0.01	0.01
Education				0.001	0.008
				0.00	0.00
log(GDP)					0.003
					0.00
log(GDP p/c)					-0.025**
					0.01
Complexity	0.013	0.028	0.033	0.061	0.062
	0.04	0.04	0.04	0.04	0.04
Complexity^2	0.002	0.005	0.004	0.002	0.002
	0.08	0.08	0.08	0.08	0.08
constant	-0.044**	-0.056*	-0.056*	-0.056*	0.049
	0.02	0.03	0.03	0.04	0.10
N	3565	3565	3565	3234	3234
R-sq	0.0013	0.0015	0.0015	0.0020	0.0044
Robust s/e	Yes	Yes	Yes	Yes	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

All regressions show the expected signs and significance for the variables of interest. While the magnitude of the coefficients are hard to interpret, the signs show an inverted U-shape effect of IPR on productivity growth rate as technological complexity increases.

Table 3.3: FE, Productivity Growth Rate

	(1)	(2)	(3)	(4)	(5)
IPR*Complexity	0.115**	0.103**	0.104**	0.117**	0.126**
	0.05	0.05	0.05	0.05	0.05
IPR*Complexity^2	-0.265**	-0.239**	-0.239**	-0.281**	-0.292**
	0.10	0.10	0.10	0.10	0.10
IPR	0.1331	0.1241	0.1441	0.1803	0.0992
	0.15	0.15	0.15	0.15	0.15
log(Exports)		0.001*	0.001**	0.001**	0.002**
		0.00	0.00	0.00	0.00
Country technology			0.004	0.011	0.017
			0.01	0.01	0.01
Education				0.002	0.006
				0.00	0.00
log(GDP)					0.001
					0.00
log(GDP p/c)					-0.015**
					0.01
Complexity	0.011	0.019	0.019	0.022	0.022
	0.04	0.04	0.04	0.04	0.04
Complexity^2	0.003	0.003	0.003	0.002	0.002
	0.08	0.08	0.08	0.08	0.08
constant	-0.042**	-0.058*	-0.058*	-0.076*	0.004
	0.02	0.03	0.03	0.04	0.11
N	3565	3565	3565	3234	3234
R-sq	0.0258	0.0260	0.0260	0.0279	0.0286
Country FE	Yes	Yes	No	No	No
Year FE	Yes	Yes	Yes	Yes	Yes
Robust s/e	Yes	Yes	Yes	Yes	Yes

* p<0.10, ** p<0.05, *** p<0.01

Once again the coefficients have the expected signs and significance, and there are no consistent differences with the OLS regressions. The effects of controls are not statistically significant, except for GDP, which is negative and significant. Smaller countries of the OECD show higher productivity growth rates than larger economies. The interpretation for this sign may be a convergence effect between OECD members.

As a robustness check, I run this regression but using export growth rate, and a lagged export growth rate as control. The reported values are in Appendix B.3. The coefficients for export growth rate and export growth rate lagged are significant in that case, but lose significance when year fixed effect are added, suggesting that this effect has the same statistical magnitude for all countries. Then year fixed effects are enough to control for the effect of lagged export growth rate.

As a robustness check, I run a quantile regression ($q=\{.2, .4, .6, .8\}$) as an alternative strategy to check for the inverted U-shape.

The results confirm the idea of IPR having a positive effect on firm productivity growth for industries of low to medium technological complexity ($q<60$). In terms of magnitude, the interacted effect of IPR and complexity on productivity growth only for industries in the 20th percentile.

Additionally, an increase on foreign IPR of one unit would increase the productivity growth rate by 1.1% more as complexity increases by one decimal. When drawing a line at the 40th percentile, this effect is still positive and significant, but the magnitude is reduced compared to industries of lower complexity. The same increase in IPR and complexity would cause an increase in productivity growth of 0.1%. The effect disappears in the 60th percentile of the conditional distribution of productivity growth, as the regressors are not statistically significant.

Table 3.4: Quantile Regression: Productivity growth and IPR

Variable	active
q20	
Complexity	.00365945
Complexity*IPR	.11521001**
IPR	.02409678***
Exports	3.043e-13*
Constant	-.17308339***
q40	
Complexity	.00564812
Complexity*IPR	.01023831*
IPR	.00419001
Exports	7.931e-15*
Constant	-.01743884
q60	
Complexity	.004512658
Complexity*IPR	-.06704492
IPR	-.00592752
Exports	1.437e-13*
Constant	.07366554***
q80	
Complexity	-.004261002
Complexity*IPR	-.12293748
IPR	-.0170026
Exports	3.850e-13***
Constant	.1801484***
N	3565

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

3.4 Concluding remarks

This chapter aims to analyze how industries' innovation is shaped by the interaction of intellectual property rights and the technological complexity of production. I endogenize the innovation decision of exporting firms, in a dynamic model of monopolistic competition where firm size and productivity depends of previous innovating efforts. Exporting firms hace potential foreign imitators, and there is an exogenous probability of imitation that depends on the foreign protection of IPR. Products have different technological complexity, which shapes the effect of foreign IPR on domestic innovation.

I simulate the model and find that complexity affects the probability of a firm dying, and the cost of imitating the product. In equilibrium, IPR generates a non-monotonicity in the effect of foreign IPR on domestic innovation. Firms in the tales of the complexity spectrum are less sensitive to changes in IPR.

Finally, I test this model using industry productivity measures from the OECD. I find evidence supporting an inverted U-shape effect of IPR on productivity sorted by technological complexity.

Appendix A

Patents, IPR, and Complexity

A.1 Proofs

Proof. **Proposition 2.2.1**

$$\frac{\partial z^R}{\partial \psi} = \frac{w_j}{P_j}\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}} + \frac{Af^R(1-\gamma(\sigma-1))\psi^{1-\gamma(\sigma-1)}w_j\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{\sigma}{\sigma-1}}}{(\sigma-1)X_jP_j}$$
$$-\frac{\psi w_j\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}}\frac{\partial P_j}{\partial \psi}}{(P_j)^2}$$

Since the price index considers all technological complexities of all varieties, then $\frac{\partial P_j}{\partial \psi} = 0$

Thus $\gamma < 1/(\sigma-1)$ is sufficient for $\frac{\partial z^R}{\partial \psi} > 0$.

If $\frac{\partial z^R}{\partial \psi} < 0$, then $\gamma(\sigma-1) - 1 < 0$ and

$$\frac{w_j}{P_j}\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}} + \frac{Af^R(1-\gamma(\sigma-1))\psi^{1-\gamma(\sigma-1)}w_j\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{\sigma}{\sigma-1}}}{(\sigma-1)X_jP_j} < 0$$

$$\Rightarrow \frac{w_j}{P_j}\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}} < \frac{Af^R(\gamma(\sigma-1)-1)\psi^{1-\gamma(\sigma-1)}w_j\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{\sigma}{\sigma-1}}}{(\sigma-1)X_jP_j}$$

$$\Rightarrow \left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{1}{\sigma-1}} < \frac{Af^R(\gamma(\sigma-1)-1)\psi^{1-\gamma(\sigma-1)}\left(\frac{Af^R\psi^{1-\gamma(\sigma-1)}}{X_j}\right)^{\frac{\sigma}{\sigma-1}}}{(\sigma-1)X_j}$$

$$\Rightarrow A^{-2}\left(f^R\right)^{-2}\left(\psi^{1-\gamma(\sigma-1)}\right)^{-2} < \frac{(\gamma(\sigma-1)-1)}{(\sigma-1)}$$

$$\Rightarrow \left(f^R\right)^{-2}\left(\psi^{1-\gamma(\sigma-1)}\right)^{-2}(\sigma-1)^{-1+2\sigma}\sigma^{-2\sigma} < \gamma(\sigma-1) - 1$$

But for $\frac{\partial z^R}{\partial \psi} < 0$ it must be that $\gamma(\sigma-1) - 1 < 0$, and since $\sigma > 1$ all terms in the LHS are positive. Then $\frac{\partial z^R}{\partial \psi} > 0$ fot all ψ and γ.

Proof. **Proposition 2.2.2**

This proof can be found in Zolas (2011), Results 2 and 3.

Decreasing in z_j^R :
$\frac{\partial r_{ij}\left(z_j^R, z^I\right)}{\partial z_j^R} = -T_j\theta\left(z_j^R\right)^{-\theta-1}\exp\left(-T_i\left(\left(z_j^R\right)^{-\theta} - \left(\frac{w_j}{w_i d_{ij}}\right)^{-\theta}\left(z^I\right)^{-\theta}\right)\right)M_j^R < 0$
Increasing in z^I :
$\frac{\partial r_{ij}\left(z_j^R, z^I\right)}{\partial z^I} = T_j\theta\left(\frac{w_j}{w_i d_{ij}}\right)^{-\theta}\left(z^I\right)^{-\theta-1}\exp\left(-T_i\left(\left(z_j^R\right)^{-\theta} - \left(\frac{w_j}{w_i d_{ij}}\right)^{-\theta}\left(z^I\right)^{-\theta}\right)\right)M_j^R >$
0

Proof. **Corollary 2.2.1**
$\frac{\partial r_{ij}\left(z_j^R, z^I\right)}{\partial \psi} = \frac{\partial r_{ij}\left(z_j^R, z^I\right)}{\partial z_j^R}\frac{\partial z^R}{\partial \psi} < 0$ by Propositions 2.2.1 and 2.2.2

Proof. **Proposition 2.2.3**
$\frac{\partial \phi(r_{ij})}{\partial \psi} = \frac{\partial \phi(r_{ij})}{\partial r_{ij}}\frac{\partial r_{ij}}{\partial \psi}$
$\frac{\partial r_{ij}}{\partial \psi} < 0$ by Corollary 2.2.1
And $\frac{\partial \phi(r_{ij})}{\partial r_{ij}} = -\frac{T_i(w_j)^\theta T_j(w_i d_{ij})^\theta\left(\overline{m}^\theta - 1\right)}{\left(r_{ij}T_j(w_i d_{ij})^\theta\left(\overline{m}^\theta - 1\right) + T_i(w_j)^\theta\right)^2} < 0$
Then $\frac{\partial \phi(r_{ij})}{\partial \psi} > 0$.

A.2 Data

A.2.1 Patent transfers and complexity

Figure A.1: Density plot of complexity

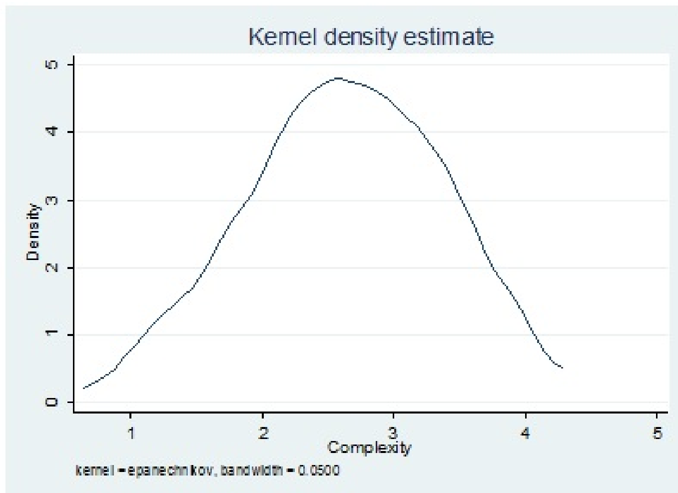


Figure A.2: Density of U.S. and Japan complexity of patents originated

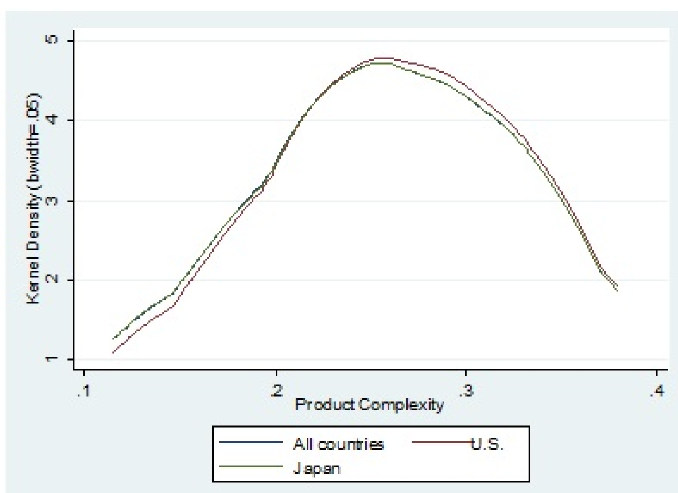


Figure A.3: Density of U.S. and China complexity of patents received

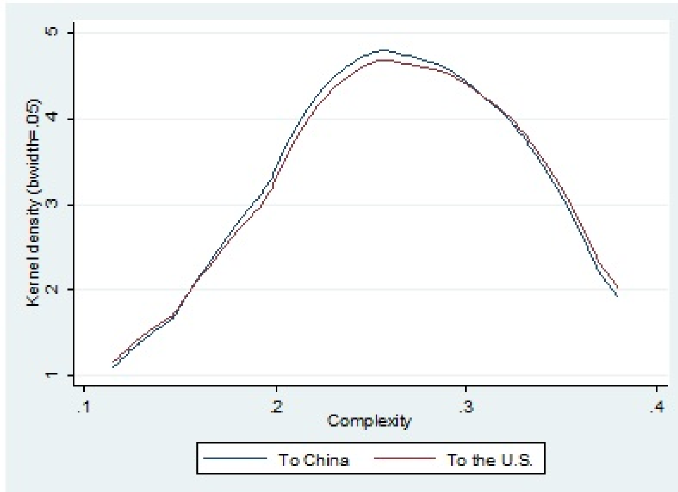


Figure A.4: Total Patents Transferred and Complexity Plot

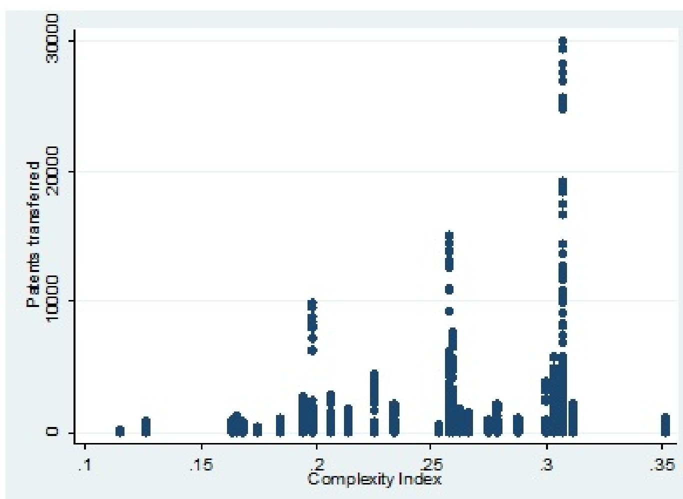


Figure A.5: Average Patents Transferred and Complexity Plot

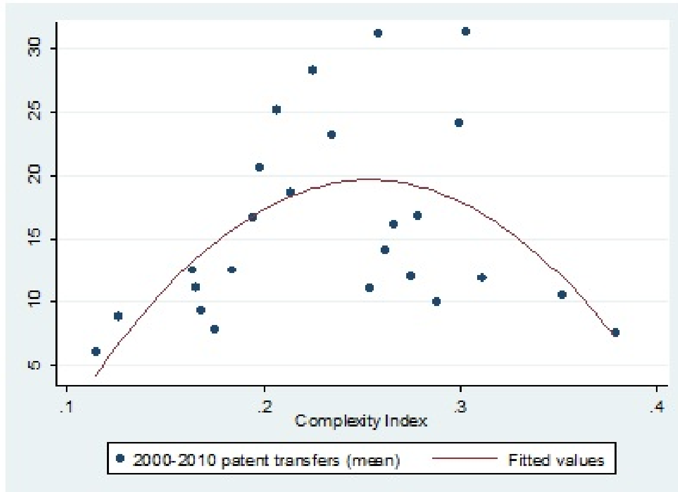


Figure A.6: Patents Transferred and Exports

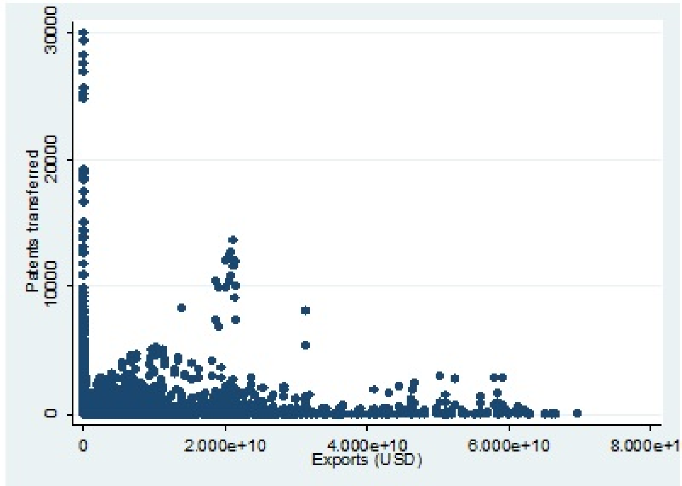


Figure A.7: Patents Transferred and Destination Country GDP per capita

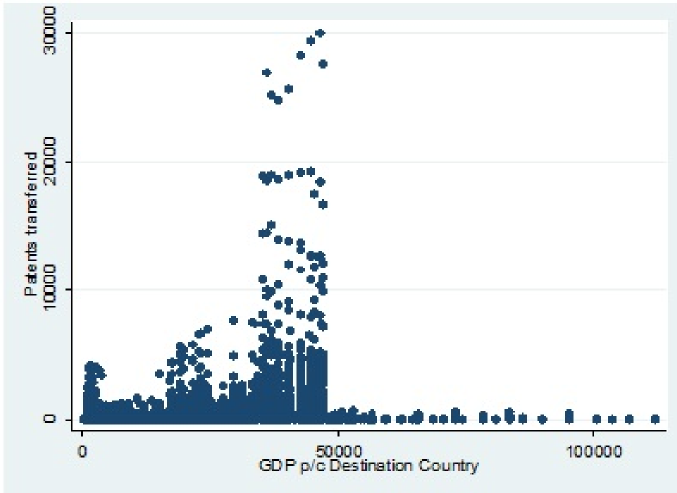


Figure A.8: Total Patents Transferred and Origin Country GDP per capita

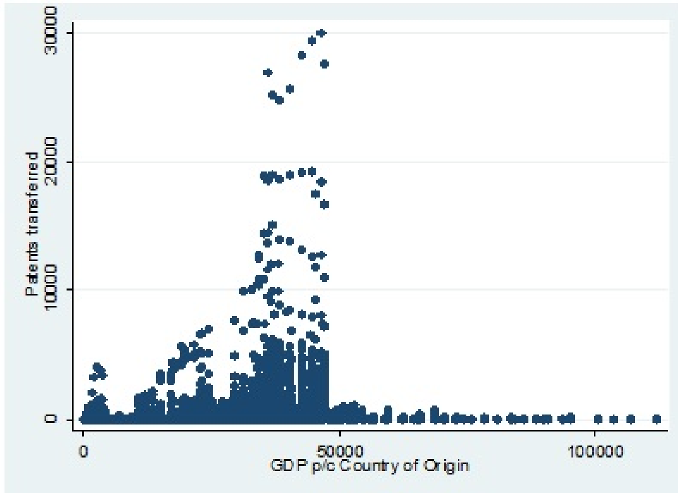


Figure A.9: Average Patents Transferred and Origin Country GDP per capita

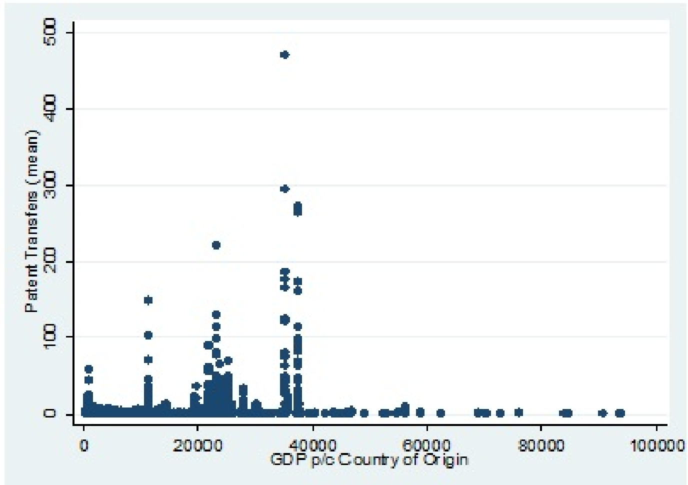


Figure A.10: Low Complexity Patent Transfers and Origin Country GDP p/c

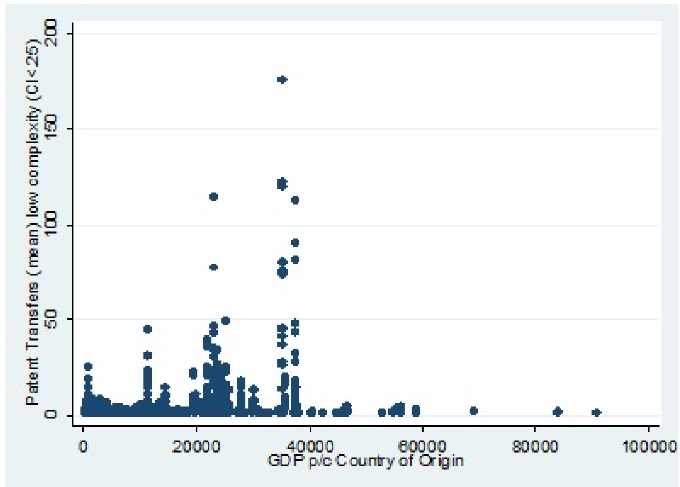


Figure A.11: Medium Complexity Patent Transfers and Origin Country GDP p/c

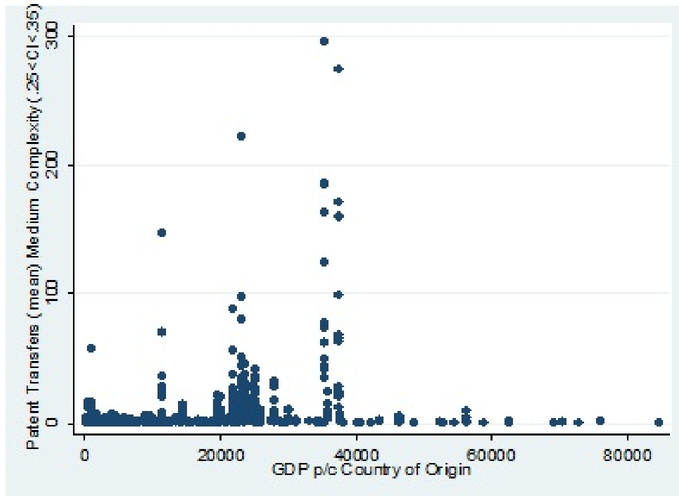


Figure A.12: High Complexity Patent Transfers and Origin Country GDP p/c

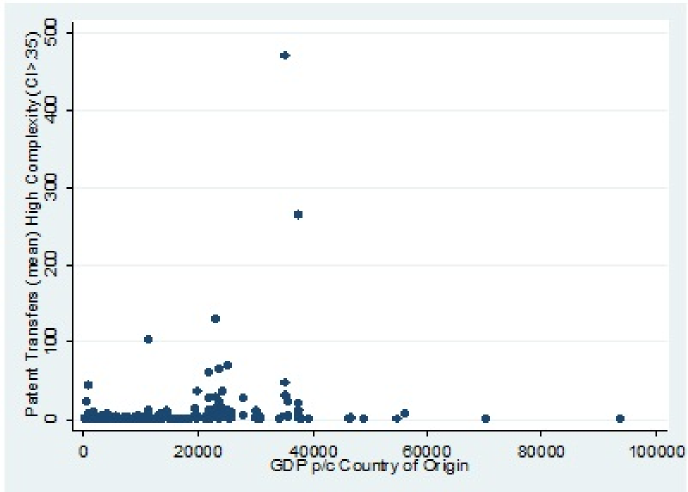
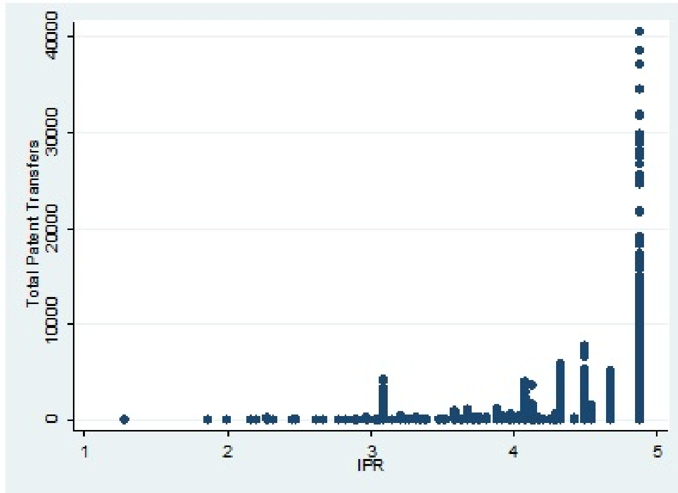


Figure A.13: Patents Transferred and Destination Country IPR



A.2.2 Complexity index: Naghavi, Spies and Toubal (2011)

O*Net provides information on importance and level of complex solving skills for 809 eight digit SOC occupations. Each occupation, o embodies a complexity of

$$\psi_o = i_o^{\alpha} + l_o^{\beta}$$

where the weights α and β give the contributions of the two complexity components: importance $i \in [1,5]$ and level $l \in [0,7]$.

The different scales of the complexity components are normalized to a $[0,1]$ scale using the min-max method.

For importance:

$$I = \frac{i_o - \min(i)}{\max(i) - \min(i)}$$

and for level:

$$L = \frac{l_o - \min(l)}{\max(l) - \min(l)}$$

As in Costinot et al. (2011), this complexity is merged with employment information from the U.S. Bureau of Labor Statistics' Occupational Employment Statistics (OES). The 1999 data contains the number of employees by occupation in every three digit industry SIC classification. The occupational intensity, b_o^k, of each industry k is given by

$$b_o^k = \frac{L_o^k}{\sum_o L^k}$$

where L_o^k is the employment level of occupation o in industry k. In their paper, Naghavi, Spies, and Toubal use the Eurostat to derive a complexity measure at the product level:

$$\psi(\omega) = \frac{x^k(\omega)}{\sum_k x^k(\omega)} \left(\psi_o b_o^k\right)$$

Where $x^k(\omega) / \sum_k x^k(\omega)$ is the share of product ω in industry k. The problem with this weight in the index at the product level, is that it artifically generates higher complexity measures for products with higher production share in a given industry. Hence, a low cost car would be more complex than a hybrid car, since there are more units produced. Because of this problem, I only use their estimates at the industry level (2 digit SIC).

Complexity rankings

Table A.1: NGT (2011) Complexity index rankings

Code	Description	Complexity
72	Computer & related services	.4221271
32	Radio, television & communication equipment & apparatus	.3798102
30	Office machinery & computers	.3790194
40	Electrical energy, gas, steam & hot water	.3515674
74	Other business services	.3246673
29	Machinery & equipment n.e.c.	.3113132
31	Electrical machinery & apparatus n.e.c.	.3073564
50	Trade, maint. & repair services of motor vehicles & mtrcls	.3033172
33	Medical, precision & optical instruments, watches and clocks	.3031925
92	Recreational, cultural & sporting services	.2997497
28	Fabricated metal products, except machinery & equipment	.2878633
27	Basic metals	.2786216
35	Other transport equipment	.2748125
12	Uranium & thorium ores	.266358
11	Crude petrol. & natural gas; services incidental to oil	.2624262
34	Motor vehicles, trailers & semi-trailers	.2596836
24	Chemicals, chemical products & man-made fibres	.2580898
23	Coke, refined petroleum products & nuclear fuels	.2537238
22	Printed matter & recorded media	.2342544
10	Coal & lignite; peat	.2317005
36	Furniture; other manufactured goods n.e.c.	.2246486
13	Metal ores	.2134478
25	Rubber & plastic products	.205822
15	Food products & beverages	.1978979
14	Other mining & quarrying products	.1938014
26	Other non-metallic mineral products	.1839178
20	Wood & products of wood & cork (excp. furniture); articles of straw	.1745415
17	Textiles	.167882
19	Leather & leather products	.1651444
21	Pulp, paper & paper products	.1634918
18	Wearing apparel; furs	.1262338
16	Tobacco products	.1146149

A.2.3 IPR index: Park (2008)

The overall score for patent right index is the sum of the five following scores.

Score 1: Coverage.

A country's legal system earns 1/8 points for each patentable of the eight following categories: (i) pharmaceuticals, (ii) chemicals, (iii) food, (iv) surgical products, (v) microorganisms, (vi) utility models, (vii) software, (viii) plant and animal varieties.

Score 2: Membership in international treaties.

A country's legal system earns 1/5 points for each of the following international treaties' membership: (i) Paris convention and revisions, (ii) Patent cooperation treaty, (iii) Protection of new varieties UPOV, (iv) Budapest treaty -microorganism deposits-, (v) TRIPS.

Score 3: Duration of protection.

A country's legal system with duration of protection x years from the date of application, earns $x/20$ or $x/17$ if it is a grant-based patent system.

Score 4: Enforcement mechanisms.

A country's legal system earns 1/3 points for each of the following mechanisms available: (i) preliminary injunctions, (ii) contributory infringement, (iii) burden of proof reversal.

Score 5: Restrictions on patent rights.

A country's legal system earns 1/3 for each restriction unavailable: (i) working requirements, (ii) compulsory licensing, (iii) revocation of patents.

Table A.2: Park (2008) IPR enforcement (i)

Country	2000	2005	Country	2000	2005	Country	2000	2005
Algeria	3.07	3.07	Egypt	3.73	3.73	Kenya	2.88	3.22
Angola	1.08	1.2	El Salv.	3.36	3.48	Korea	4.13	4.33
Argentina	3.98	3.98	Ethiopia	2	2.13	Liberia	2.11	2.11
Australia	4.17	4.17	Fiji	2.4	2.4	Lithuania	3.48	4
Austria	4.33	4.33	Finland	4.54	4.67	Luxemgb.	4.14	4.14
Banglad.	1.87	1.87	France	4.67	4.67	Madagas.	2.31	2.31
Belgium	4.67	4.67	Gabon	2.23	3.06	Malawi	2.15	2.15
Benin	2.1	2.93	Germany	4.5	4.5	Malaysia	3.03	3.48
Bolivia	3.43	3.43	Ghana	3.15	3.35	Mali	2.1	2.93
Botswana	3.32	3.52	Greece	3.97	4.3	Malta	3.18	3.48
Brazil	3.59	3.59	Grenada	2.48	3.02	Mauritan.	2.43	3.27
Bulgaria	4.42	4.54	Guatemala	1.28	3.15	Mauritius	1.93	2.57
Burk. Faso	2.1	2.93	Guyana	1.33	1.78	Mexico	3.68	3.88
Burma	0.2	0.2	H. Kong	3.81	3.81	Morocco	3.06	3.52
Burundi	2.15	2.15	Haiti	2.9	2.9	Mozamb.	1.06	2.52
Cameroon	2.23	3.06	Honduras	2.86	2.98	N. Zealand	4.01	4.01
Canada	4.67	4.67	Hungary	4.04	4.5	Nepal	1.79	2.19
Cent. Afr.	2.1	2.93	Iceland	3.38	3.51	Netherl.	4.67	4.67
Chad	2.1	2.93	India	2.27	3.76	Nicaragua	2.16	2.97
Chile	4.28	4.28	Indonesia	2.47	2.77	Niger	2.1	2.93
China	3.09	4.08	Iran	1.91	1.91	Nigeria	2.86	3.18
Colombia	3.59	3.72	Iraq	2.12	1.78	Norway	4.13	4.29
Congo, Rep.	2.23	3.06	Ireland	4.67	4.67	P.N.Guin.	1.4	1.6
Cost. Rica	2.89	2.89	Israel	4.13	4.13	Pakistan	2.2	2.4
Cyprus	3.48	3.48	Italy	4.67	4.67	Panama	3.64	3.64
Czech Republic	3.21	4.33	Ivory Cst.	2.36	3.06	Paraguay	2.39	2.89
Denmark	4.67	4.67	Jamaica	3.06	3.36	Peru	3.32	3.32
Dom. Rep.	2.45	2.82	Japan	4.67	4.67	Philipp.	3.98	4.18
Ecuador	3.73	3.73	Jordan	3.03	3.43	Poland	3.92	4.21

Table A.3: Park (2008) IPR enforcement (ii)

Country	2000	2005	Country	2000	2005	Country	2000	2005
Portugal	4.13	4.5	Sudan	2.61	2.61	U.S.A.	4.88	4.88
Romania	3.72	4.17	Swazil.	2.43	2.4.	Uganda	2.98	2.98
Russia	3.68	3.68	Sweden	4.54	4.54	Ukraine	3.68	3.68
Rwanda	2.28	2.28	Switzerl.	4.33	4.33	Uruguay	3.27	3.39
S. Africa	4.25	4.25	Syria	1.99	2.19	Venezuela	3.32	3.32
S. Leone	2.98	2.98	Taiwan	3.29	3.74	Vietnam	2.9	3.03
Saudi Ar.	1.83	2.98	Tanzania	2.64	2.64	Dem. Congo	1.78	2.23
Senegal	2.1	2.93	Thailand	2.53	2.66	Zambia	1.74	1.94
Singapore	4.01	4.21	Togo	2.1	2.93	Zimbabwe	2.6	2.6
Slovak Republic	2.96	4.21	Trin.& Tob.	3.63	3.75			
Somalia	2.13	2.13	Tunisia	2.32	3.25			
Spain	4.33	4.33	Turkey	4.01	4.01			
Sri. Lanka	3.11	3.11	U.K.	4.54	4.54			

A.2.4 CPC-ISIC Concordance

Table A.4: CPC-ISIC Concordance

ISIC	CPC	ISIC	CPC	ISIC	CPC	ISIC	CPC
01 02	A01	29	B26	15	C13	29	F24
15	A21	20	B27	19	C14	29	F25
15	A22	26	B28	27	C21	29	F26
15	A23	25	B29	13	C22	29	F27
16	A24	29	B30	27	C23	29	F28
18	A41	21	B31	28	C25	28	F41
18	A42	22	B41	26	C30	28	F42
19	A43	22	B42	24	C40	32	G01
18	A44	30	B43	17	D01	33	G02
19	A45	30	B44	17	D02	33	G03
20	A46	34	B60	17	D03	33	G04
36	A47	35	B61	17	D04	32	G05
85	A61	34	B62	17	D05	32	G06
85	A62	35	B63	17	D06	33	G07
92	A63	35	B64	17	D07	33	G08
24	B01	31	B81	17	D10	32	G09
24	B02	31	B82	21	D21	33	G10
24	B03	12	C01	40	E03	72	G11
29	B04	40	C02	14	E21	33	G12
24	B05	26	C03	29	F01	23	G21
29	B06	26	C04	29	F02	31	H01
29	B07	24	C05	29	F03	31	H02
90	B08	24	C06	29	F04	31	H03
90	B09	24	C07	31	F15	31	H04
14	B21	24	C08	31	F16	31	H05
24	B22	24	C09	31	F17		
24	B23	11	C10	31	F21		
14	B24	24	C11	31	F22		
29	B25	15	C12	31	F23		

A.3 Regressions

Table A.5: IPR OLS, patents granted

Patent Counts	OLS 1	OLS 2	OLS 3	OLS 4	OLS 5
IPR*Complexity	182.184***	174.707***	14.256	39.327*	83.288***
	8.92	8.91	16.10	16.36	9.01
IPR*Complexity^2	-251.885***	-259.367***	35.586	6.664	-102.846*
	18.23	18.21	30.65	31.17	40.35
Exports		0.000***	0.000***	0.000***	0.000***
		0.00	0.00	0.00	0.00
Imports		-0.000*	-0.000	-0.000	-0.000
		0.00	0.00	0.00	0.00
IPR			28.654***	2.593	-10.951**
			2.40	2.81	3.65
Orig. Tech.				104.672***	38.579***
				-1.79	-6.23
Tech. Diff.					-31.410***
					6.03
GDP p/c				-0.000***	0.00
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					0.00
					0.00
constant	-96.804***	-89.814***	-123.879***	-58.515***	-30.031**
	4.71	4.71	5.50	7.32	9.38
R-sqr	0.0036	0.0061	0.0066	0.0233	0.0610
N	310536	310536	303094	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes

* p<0.05, ** p<0.01, *** p<0.001

Table A.6: IPR FE, patents granted

Patent Counts	FE 1	FE 2	FE 3	FE 4	FE 5
IPR*Complexity	185.009***	179.624***	14.744	40.319*	86.371***
	9.01	9.00	16.10	16.36	21.24
IPR*Complexity^2	-256.746***	-268.143***	34.983	5.332	-107.765**
	18.38	18.36	30.65	31.17	40.31
Exports		0.000***	0.000***	0.000***	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	-0.000	-0.000	-0.000
		0.00	0.00	0.00	0.00
IPR			29.711***	0.481	-12.624***
			2.41	2.83	3.66
Orig. Tech.				104.857***	22.889***
				1.79	6.88
Tech. Diff.					-48.193***
					6.69
GDP p/c				-0.00	0.00
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					0.00
					0.00
constant	-98.461***	-92.636***	-128.795***	-54.104***	-30.208**
	4.77	4.77	5.59	7.37	9.44
R-sqr	0.0037	0.0063	0.0068	0.0238	0.0629
N	310536	310536	303094	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.7: IPR PPML, patents granted

Patent Counts	PPML 1	PPML 2	PPML 3	PPML 4	PPML 5
IPR*Complexity	9.222***	8.867***	2.584***	2.953***	4.558***
	0.35	0.35	0.59	0.55	0.61
IPR*Complexity^2	-13.538***	-13.195***	-2.481*	-2.694*	-5.711***
	0.73	0.73	1.19	1.13	1.16
Exports		0.000***	0.000***	0.00	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	-0.000	-0.000	-0.000
		0.00	0.00	0.00	0.00
IPR			1.359***	0.455***	-0.441***
			0.11	0.08	0.11
Orig. Tech.				1.969***	2.210***
				0.09	0.17
Tech. Diff.					-0.205
					0.14
GDP p/c				-0.000***	-0.000***
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					-0.000***
					0.00
constant	-3.125***	-2.857***	-4.985***	-2.113***	0.261
	0.20	0.19	0.30	0.20	0.33
N	310536	310536	303094	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.8: Complexity OLS, patents granted

Patent Counts	OLS 1	OLS 2	OLS 3	OLS 4	OLS 5
Complexity	933.039***	971.044***	1123.743***	1551.999***	2429.122***
	281.62	281.24	287.69	292.70	426.06
Complexity^2	-678.503	-1123.947*	-1397.381*	-1918.340***	-3917.894***
	535.40	534.89	-131.98	557.36	808.21
Exports		0.000***	0.000***	0.000***	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			122.150***	43.274***	11.803
			5.33	7.96	11.60
Orig. Tech.				406.336***	158.319***
				7.46	29.26
Tech. Diff.					-123.138***
					28.32
GDP p/c				-0.000***	0.00
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					0.002
					0.00
constant	-97.634**	-90.701*	-629.134***	-468.823***	-475.261***
	35.91	35.86	43.48	48.36	70.38
R-sqr	0.0007	0.0034	0.0051	0.0192	0.0608
N	310558	310558	310558	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.9: Complexity FE, patents granted

Patent Counts	FE 1	FE 2	FE 3	FE 4	FE 5
Complexity	934.368***	972.711***	1131.178***	1566.365***	2485.384***
	281.62	281.24	287.68	292.66	425.83
Complexity^2	-681.982	-1125.095*	-1406.935*	-1937.591***	-4011.799***
	535.40	534.89	547.36	557.29	807.74
Exports		0.000***	0.000***	0.000***	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			125.989***	36.476***	7.311
			5.41	8.07	11.67
Orig. Tech.				406.975***	90.246**
				7.46	32.31
Tech. Diff.					-195.226***
					31.42
GDP p/c				-0.000	-0.001
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					0.003
					0.00
constant	-97.729**	-91.076*	-646.938***	-455.787***	-486.515***
	35.91	35.86	43.69	48.48	70.56
R-sqr	0.0008	0.0035	0.0052	0.0195	0.0450
N	310558	310558	310558	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.10: Complexity PPML, patents granted

Patent Counts	PPML 1	PPML 2	PPML 3	PPML 4	PPML 5
Complexity	21.788***	21.543***	21.721***	23.419***	31.238***
	3.08	3.12	3.10	2.92	3.03
Complexity^2	-28.187***	-29.219***	-29.882***	-30.726***	-46.204***
	6.00	6.13	6.13	5.85	5.63
Exports		0.000***	0.000***	0.00	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			1.950***	1.031***	0.355***
			0.09	0.07	0.11
Orig. Tech.				2.289***	2.433***
				0.10	0.21
Tech. Diff.					-0.168
					0.18
GDP p/c				-0.000***	-0.000***
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
Distance					-0.000***
					0.00
constant	0.824*	0.913*	-7.714***	-4.935***	-3.537***
	0.38	0.38	0.54	0.45	0.59
N	310558	310558	310558	296041	80661
Robust s/e	Yes	Yes	Yes	Yes	Yes

* p<0.05, ** p<0.01, *** p<0.001

Table A.11: OLS, patent applications

Patent Counts	OLS 1	OLS 2	OLS 3	OLS 4	OLS 5
Complex	1349.225**	1233.925*	1360.049*	1194.487**	1124.585**
	520.56	520.00	259.40	264.32	265.07
Complex^2	-9794.318***	-9002.430***	-9234.160***	-9305.964***	-9172.777***
	1572.43	1570.98	921.82	524.51	540.57
IPR*Compl	2076.623***	1798.687***	1852.808	1752.206	1724.098*
	346.83	346.61	1143.19	1167.40	870.87
IPR*Compl^2	-69.351***	-35.833***	-65.285***	-71.676***	-86.201***
	12.70	12.60	6.64	6.62	6.15
Exports		0.000***	0.000***	0.00***	0.000***
		0.00	0.00	0.00	0.00
Imports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			3.815	-103.472	-104.174
			76.78	78.51	78.75
Orig. Tech.				406.965***	465.833***
				7.45	20.96
Tech. Diff.					59.765**
					20.34
GDP p/c				-0.001***	-0.001***
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
constant	-108.963**	-101.916**	-118.257	164.287	174.090
	36.70	36.66	330.96	337.89	339.02
N	310303	310303	310303	310303	310303
Robust s/e	Yes	Yes	Yes	Yes	Yes
R-sq	0.0032	0.0055	0.0055	0.0196	0.0197

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.12: FE, patent applications

Patent Counts	FE 1	FE 2	FE 3	FE 4	FE 5
Complex	1290.631*	1130.311*	1447.103**	1266.859**	1247.629**
	521.38	520.83	259.13	264.19	265.04
Complex^2	-9713.354***	-8836.403***	-9418.454*	-9470.415**	-9439.588*
	1573.28	1571.86	421.71	502.81	503.96
IPR*Compl	2056.789***	1757.756***	1893.695**	1786.236*	1779.966**
	347.04	346.84	114.31	116.73	117.07
IPR*Compl^2	-54.433	-9.927	-83.902 ***	-58.090***	-62.041***
	10.2	10.2	6.01	6.13	6.15
Exports		0.000***	0.000***	0.00***	0.000***
		0.00	0.00	0.00	0.00
Exports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			9.583	-109.148	-109.279
			76.79	78.51	78.75
Orig. Tech.				407.622***	426.022***
				7.45	22.22
Tech. Diff.					17.705
					21.71
GDP p/c				-0.000	-0.000
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
constant	-110.030**	-103.269**	-144.322	172.555	175.787
	36.70	36.66	330.99	337.86	338.99
N	310303	310303	310303	310303	310303
Robust s/e	Yes	Yes	Yes	Yes	Yes
R-sq	0.0033	0.0056	0.0056	0.0199	0.0200
Year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table A.13: PPML, patent applications

Patent Counts	PPML 1	PPML 2	PPML 3	PPML 4	PPML 5
Complex	-2.678	-8.236	156.186**	97.268***	95.127***
	6.18	5.93	45.84	24.33	24.44
Complex^2	-65.165*	-45.032	-284.264**	-234.774***	-189.225***
	23.60	22.85	90.73	48.46	48.70
IPR*Compl	7.21***	1.599	61.205*	39.262**	31.369***
	1.58	5.64	20.76	11.54	11.59
IPR*Compl^2	2.98	7.236***	-29.135*	-16.112**	-11.362*
	5.74	1.55	10.50	5.79	5.82
Exports		0.000***	0.000***	0.00	0.000
		0.00	0.00	0.00	0.00
Imports		0.000	0.000	0.000	0.000
		0.00	0.00	0.00	0.00
IPR			5.262**	1.236**	2.236***
			1.27	0.69	0.70
Orig. Tech.				2.002**	2.036***
				0.05	0.10
Tech. Diff.					-0.045
					0.09
GDP p/c				-0.000***	-0.000***
				0.00	0.00
GDP				0.000***	0.000***
				0.00	0.00
constant	0.915*	0.894***	-11.236**	-10.021***	-10.115***
	0.33	0.33	5.53	2.91	2.93
N	310303	310303	310303	310303	310303
Robust s/e	Yes	Yes	Yes	Yes	Yes

*

p<0.05, ** p<0.01, *** p<0.001

Table A.14: Fixed effects with FDI

	FE 1	FE 2	FE 3	FE 4
Complex	325.32*	265.03**	115.51*	108.50*
Complex_sq	-659.15***	-877.12***	-1022.6***	-877.365***
Complex*IPR	1308.98**	1003.65	1089.62*	1044.77*
Complex_sq*IPR	-775.22*	-588.17	-602.22*	-403.32**
IPR		1.89	1.17	1.03
Exports	0.000***	0.000***	0.000***	0.000***
Imports	-0.000	-0.000	-0.000	-0.000
FDI	0.000	0.000	0.000	0.000
Tech. Origin			3.66**	8.78***
Tech. Diff.				-1.66**
GDP p/c		-0.000	0.000	0.000
GDP		0.000***	0.000***	0.000***
Constant	13.362***	14.786***	17.263***	17.596***
N	45533	45533	45533	45533
R-sq	0.0066	0.0098	0.019	0.021
Robust s/e	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No
Year FE	Yes	Yes	Yes	Yes

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Appendix B

Innovation, IPR, and Complexity

B.1 Simulations: IPR and Complexity on Firm Productivity Growth

Figure B.1: Firm Innovation, Very Low Complexity

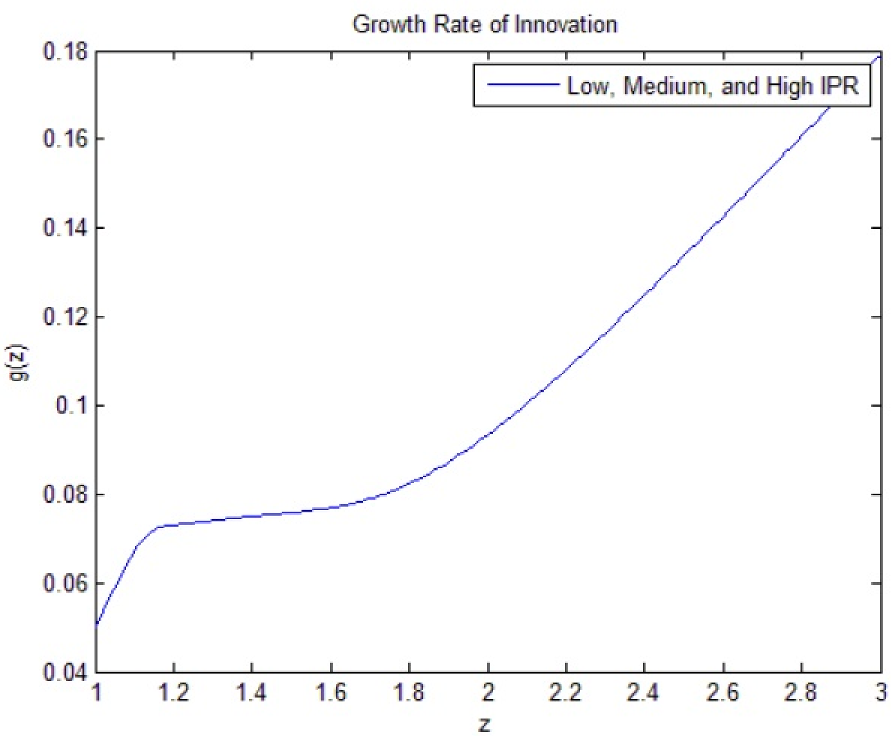


Figure B.2: Firm Innovation, Low Complexity

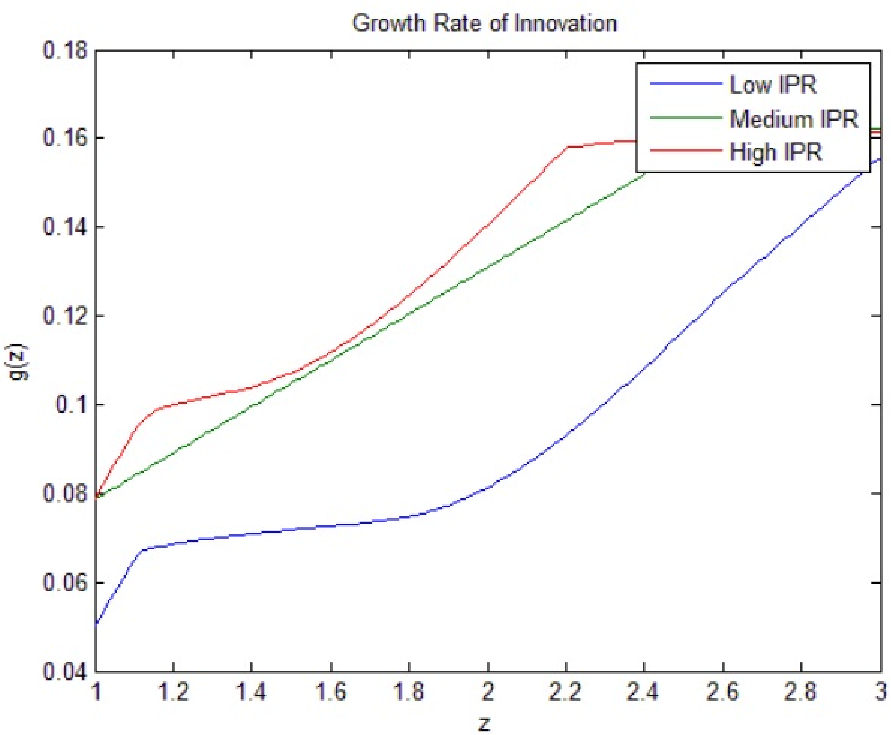


Figure B.3: Firm Innovation, Medium Complexity

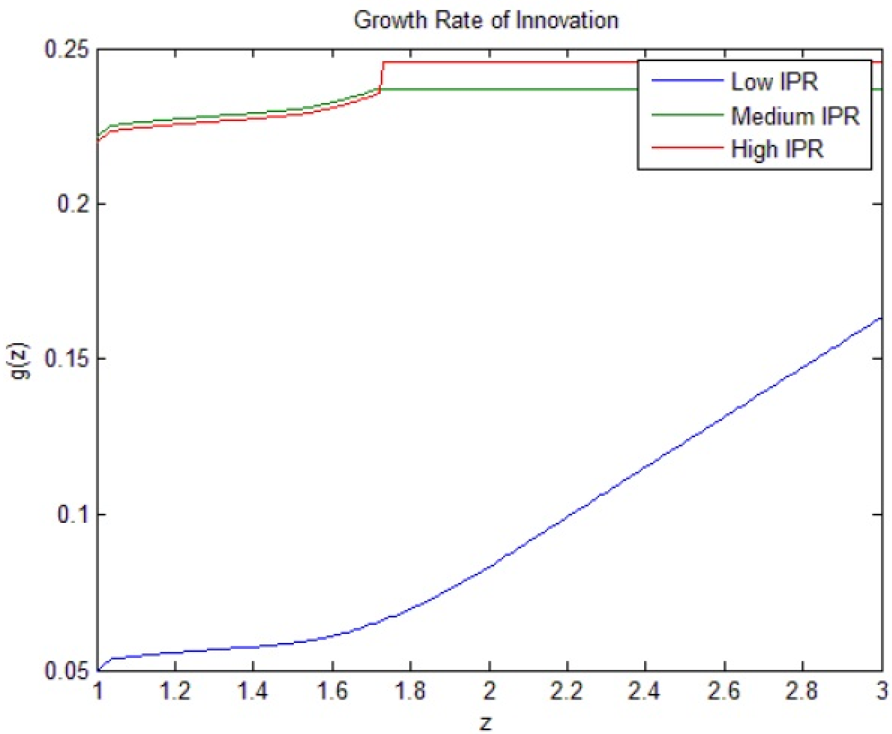


Figure B.4: Firm Innovation, High Complexity

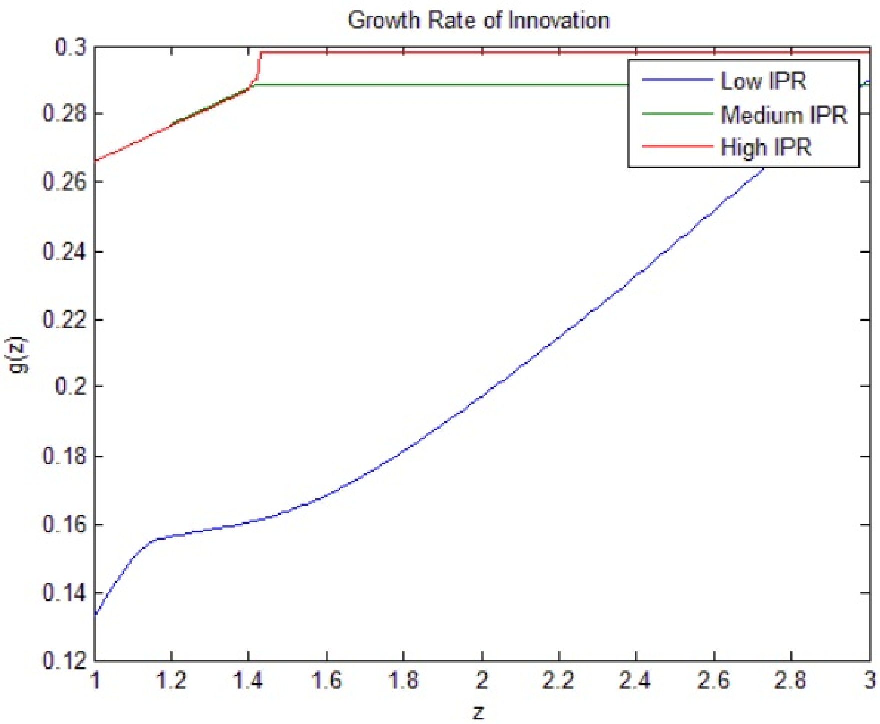
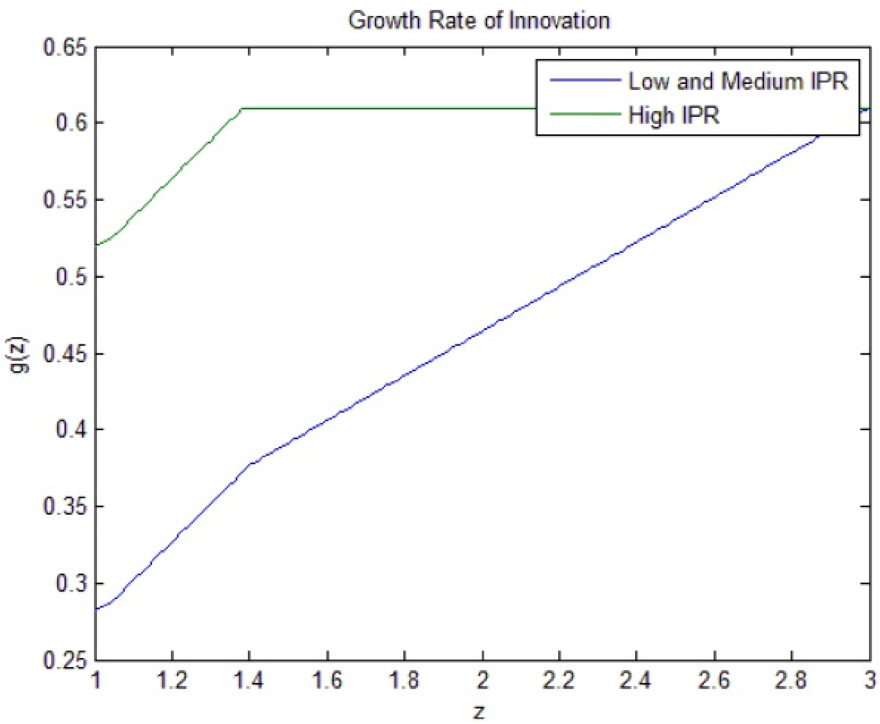


Figure B.5: Firm Innovation, Very High Complexity



B.2 Simulations: IPR and Complexity on Firm Size Distribution

Figure B.6: Firm Size Distribution, Very Low Complexity

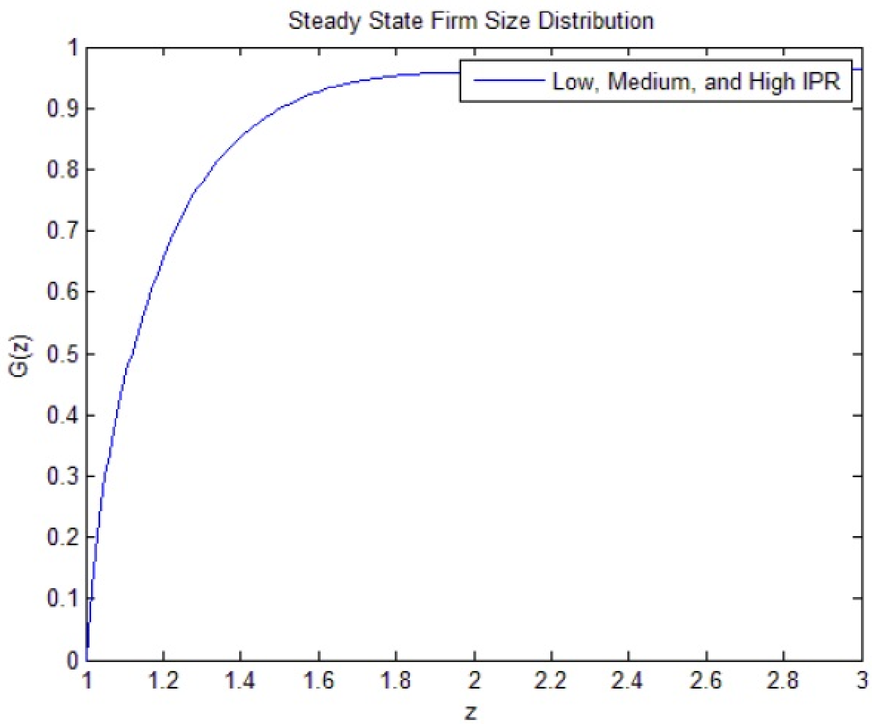


Figure B.7: Firm Size Distribution, Low Complexity

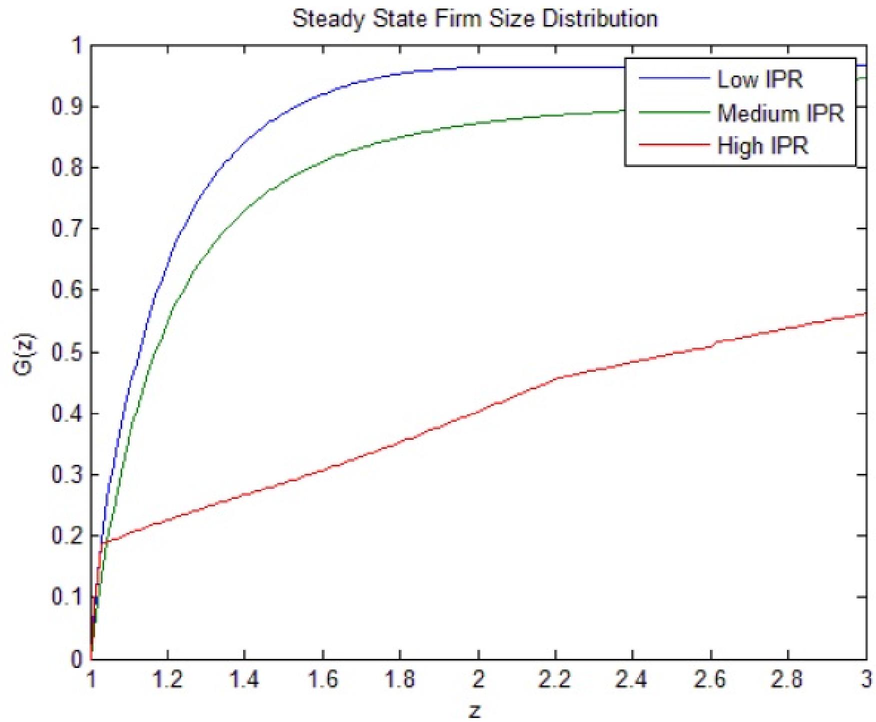


Figure B.8: Firm Size Distribution, Medium Complexity

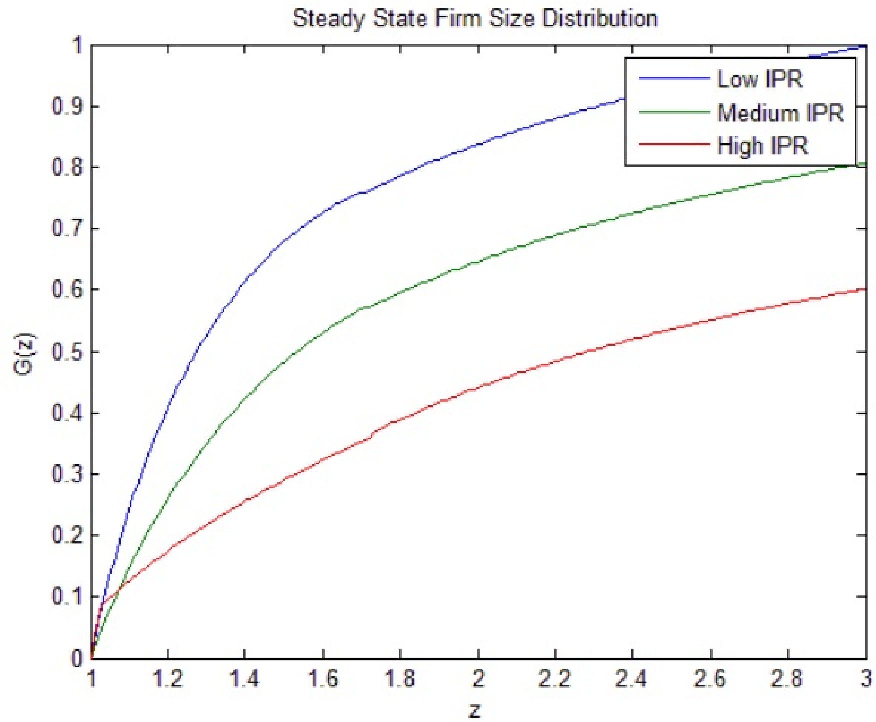


Figure B.9: Firm Size Distribution, High Complexity

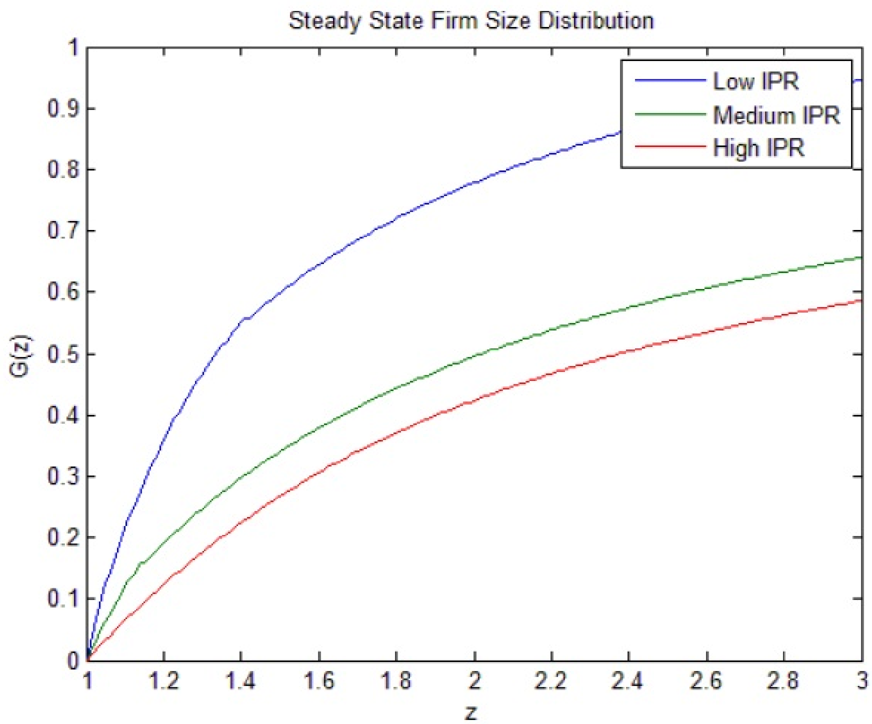
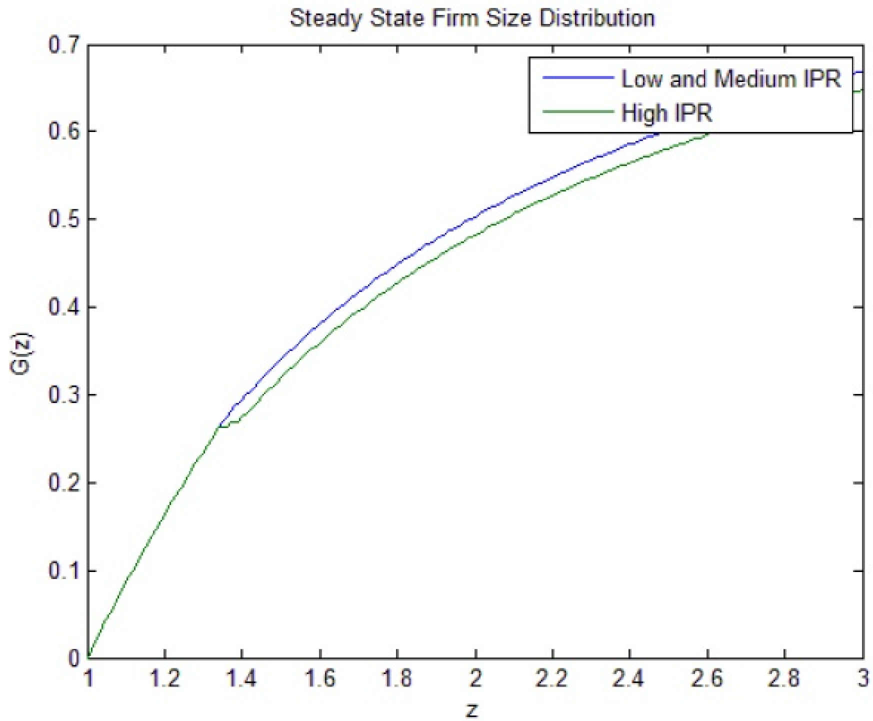


Figure B.10: Firm Size Distribution, Very High Complexity



B.3 Empirical Analysis

B.3.1 Time and Country Variation of Industry Productivity

Figure B.11: Time and Country Variation of Industry Productivity (i)

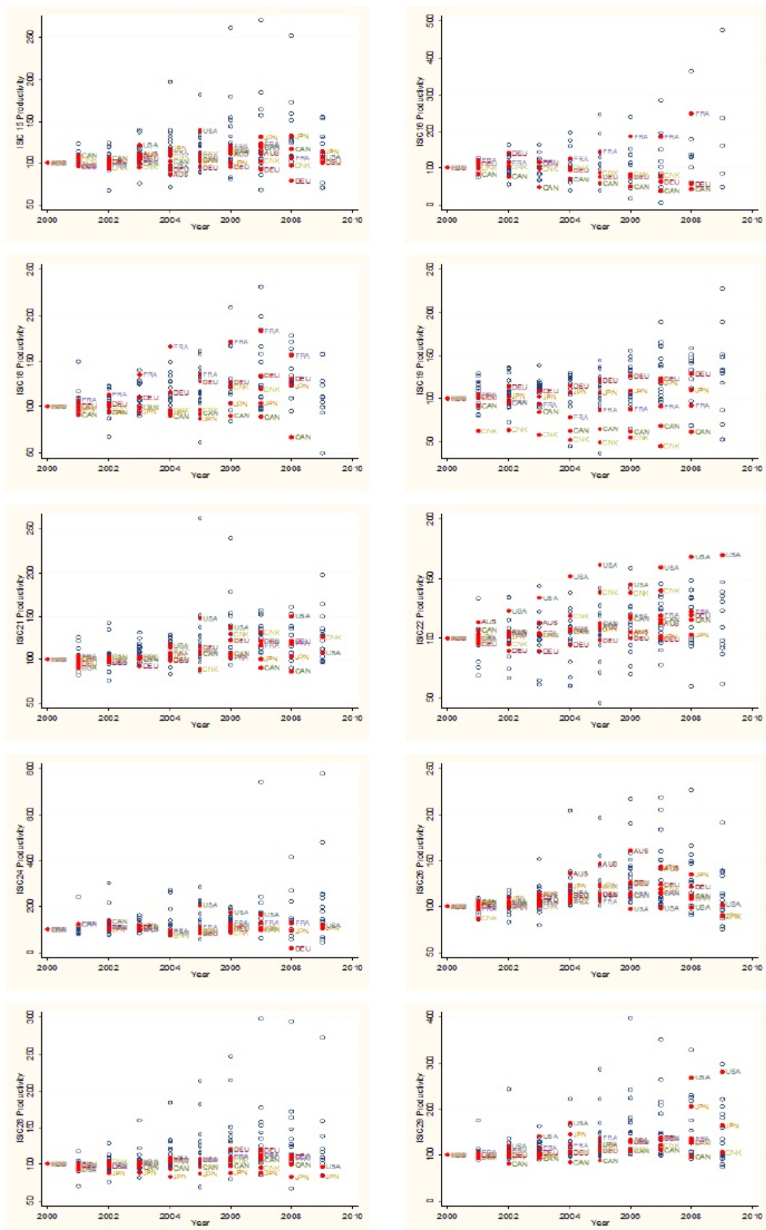
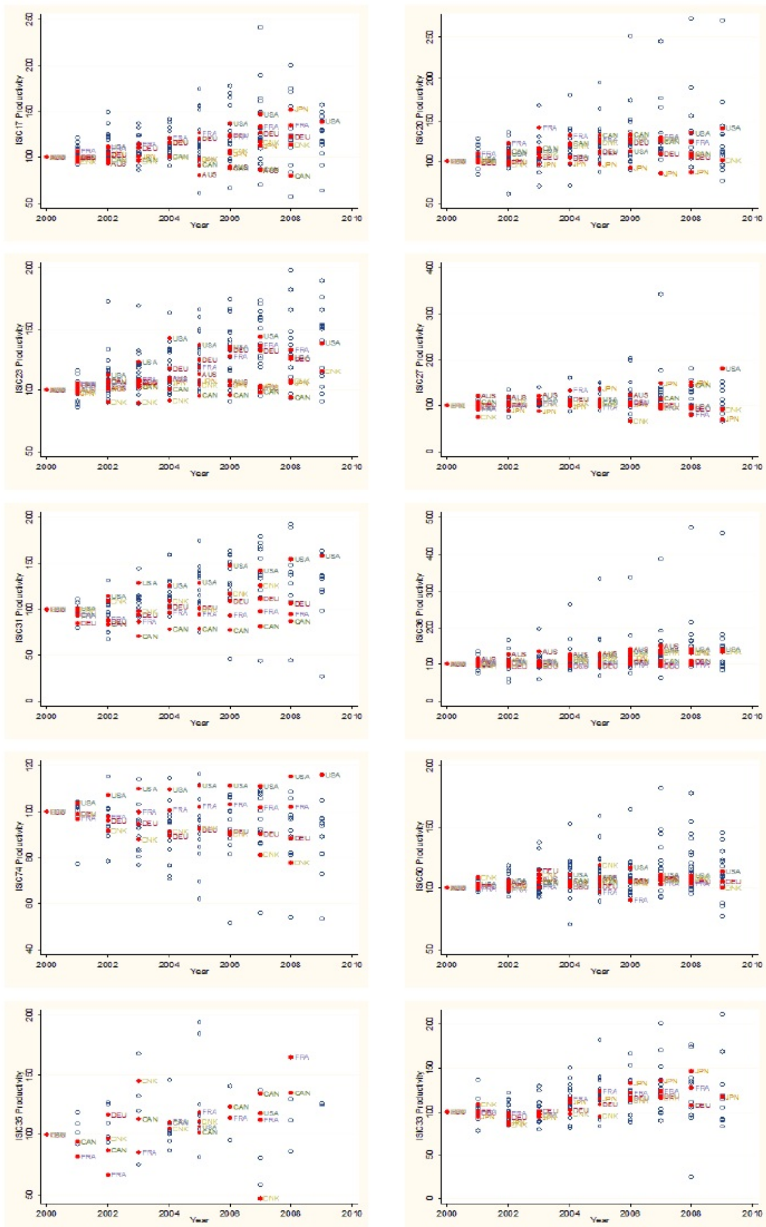


Figure B.12: Time and Country Variation of Industry Productivity (ii)



B.3.2 Regressions

Table B.1: OLS, Productivity Growth Rate

	(1)	(2)	(3)	(4)	(5)
IPR*Complexity	0.121**	0.125**	0.127**	0.133**	0.137**
	0.05	0.05	0.05	0.05	0.05
IPR*Complexity^2	-0.276**	-0.272**	-0.274**	-0.286**	-0.293**
	0.10	0.12	0.12	0.12	0.11
Exp. growth rate		0.025**	0.025**	0.024**	0.023*
		0.01	0.01	0.01	0.01
Exp. gr. rate (lag)		-0.000	-0.000	-0.000	-0.000
		0.00	0.00	0.00	0.00
Country technology			0.013	0.026*	0.022
			0.01	0.01	0.02
Education				0.002	0.009
				0.00	0.01
log(GDP)					0.008
					0.00
log(GDP p/c)					-0.026**
					0.01
constant	-0.044**	-0.050*	-0.052*	-0.063*	-0.043
	0.02	0.02	0.03	0.04	0.13
N	3565	3092	3092	2796	2796
R-sq	0.0013	0.0046	0.0049	0.0057	0.0076
Year FE	Yes	Yes	Yes	Yes	Yes
Robust s/e	Yes	Yes	Yes	Yes	Yes

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

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