Three Essays on Intellectual Property Rights and International Technology Transfer

Codrin Nedita

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Approved by:

Prof. Patrick Conway,
Advisor

Prof. Anusha Chari

Prof. Saraswata Chaudhuri

Prof. Alfred Field

Prof. Sudhanshu Handa

Abstract

CODRIN NEDITA: Three Essays on Intellectual Property Rights and International Technology Transfer.
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Developing countries today face external pressures to implement stronger intellectual property rights (IPRs). These countries are in general characterized as "imitators" that learn from technology transferred from innovating (industrialized) countries. Therefore, implementing IPRs would seem counterintuitive for developing countries as it restricts their ability to imitate. However, the true impact of IPR policy in developing countries remains largely unclear. My research unravels some of the links between IPRs, and technology transfer issue in the following three essays.

My first essay focuses on the Indian pharmaceutical market. I describe the transition dynamics of imposing stronger IPRs in a theoretical model and I test the implications of this model for the adjustment path of innovation, imitation and R&D offshoring using a panel of 354 Indian pharmaceutical firms over the period 1989 to 2008. I find that that innovation behaves as expected while imitation exhibits an unexpected increase after the announcement and decreases after the policy change. To better understand this transition, the second essay examines the short-run and long-run effects of stronger IPRs within two types of endogenous product-cycle models developed by Grossman and Helpman.

In my third essay I analyze the offshoring decision of companies for either forming a joint venture with a local firm or entering a contractual partnership, with a special focus on the research and development activity. First I present a theoretical model that describes this decision and then I test the implications of the model in the pharmaceutical market for a panel of 89 countries over the period 1990 to 2009. I find that weak IPRs in the destination country support a joint venture partnership to reduce the risk of knowledge leakage while large fixed costs of establishing a joint venture supports a contractual partnership.

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Chapter 1

Symbol	Definition
g	Innovation rate
m	Imitation rate
n	Number of products society knows how to produce
$\dot{n}$	The first derivative of n with respect to time
n_N	Number of products that the South has not yet imitated
n_S	Number of products that the South produces
U	Lifetime utility
ρ	Subjective discount rate
$u(t)$	Instantaneous utility
$\mathrm{x}(j,t)$	Consumption of product j at time t
α	A measure of substitutability
ε	Elasticity of demand
$\mathrm{p}(j,t)$	Price of product j at time t
$P(t)$	Price index at time t
$E(t)$	Aggregate spending on consumer goods at time t
$\dot{E}(t)$	The first derivative of consumption spending with respect to time
$r(t)$	Interest rate at time t
a_N	The unit labor requirement for a Northern firm
a_S	The unit labor requirement for a Southern firm
k	A parameter that measures IPR protection intensity
w_N	Northern wage
w_S	Southern wage

Symbol	Definition
π_N	Instantaneous Northern profits
π_S	instantaneous Southern profits
v_N	The present value of expected stream of Northern profits
v_S	The present value of expected stream of Southern profits
p_N	Northern monopoly price
p_S	Southern monopoly price
x_N	Northern sales
x_N	Southern sales
L_N	Northern labor supply
L_S	Southern labor supply
ζ	Fraction of goods that have not been imitated
t_0	Announcement date
t_1	Policy implementation date
t_2	New steady state date
G_{it}	Innovation for firm i at time t
M_{it}	Imitation for firm i at time t
O_{it}	Offshoring to firm i at time t
X_t	Time specific effects that reflects industry or macro-level changes
Y_{it}	Observed differences in plant characteristics
Z_t	Dummy variable
ϵ_{it}	Random noise
μ_i	Time invariant unobservable firm effect
ν_{it}	Part of the error term uncorrelated with the explanatory variables

Chapter 2

Symbol	Definition
g	Innovation rate
m	Imitation rate
n	Number of products society knows how to produce
$\dot{n}$	The first derivative of n with respect to time
n_N	Number of products that the South has not yet imitated
n_S	Number of products that the South produces
U	Lifetime utility
ρ	Subjective discount rate
$u(t)$	Instantaneous utility
$\mathrm{x}(j,t)$	Consumption of product j at time t
α	A measure of substitutability
ε	Elasticity of demand
$\mathrm{p}(j,t)$	Price of product j at time t
$P(t)$	Price index at time t
$E(t)$	Aggregate spending on consumer goods at time t
$\dot{E}(t)$	The first derivative of consumption spending with respect to time
$r(t)$	Interest rate at time t
a_N	The unit labor requirement for a Northern firm
a_S	The unit labor requirement for a Southern firm
a	Represents a productivity parameter in innovation
l	Labor employed in R&D
K_n	The cumulative stock of knowledge in the inventive activity
μ	A parameter that measures the decline in the rate of imitation when imitation is exogenous

Symbol	Definition
k	A parameter that measures IPR protection intensity when imitation is endogenous
w_N	Northern wage
w_S	Southern wage
π_N	Instantaneous Northern profits
π_S	instantaneous Southern profits
v_N	The present value of expected stream of Northern profits
v_S	The present value of expected stream of Southern profits
p_N	Northern monopoly price
p_S	Southern monopoly price
x_N	Northern sales
x_N	Southern sales
L_N	Northern labor supply
L_S	Southern labor supply
ζ	Fraction of goods that have not been imitated
Λ	Characteristic vector associated with the negative characteristic root
$x_\omega(i,t)$	The consumption of quality level ω of product $i \in [0,1]$ at time t
$q_\omega(i)$	The quality of the product offered.
$R(t)$	The cumulative interest factor up to time t
$A(0)$	The value of initial asset holdings
$Y(t)$	Aggregate labor income of all consumers
$p_\omega(i,t)$	The price of a product i of quality ω at time t
λ	Quality increment
ι	R&D intensity

Chapter 3

Symbol	Definition
γ	The risk of imitation when buying R&D
μ	The risk of imitation when creating a joint venture
ρ	Slope of the linear function that describes the risk of imitation when buying R&D
η	Slope of the linear function that describes the risk of imitation when creating a joint venture
π_H	Profits if the firm performs R&D at home
π_{JV}	Profits if the firm forms a joint venture with a Southern to performs R&D
π_{BUY}	Profits if the firm forms is buying R&D from a Southern firm
p_N	Price of output
w_N	Northern wage
w_S	Southern wage
x_N	Demand for the product
α	Horizontal intercept of the demand
β	Slope of the inverse demand
ε	Independent and identically distributed error term associated with the demand
F	Fixed cost of establishing a joint venture in the destination country
Z_H	Explanatory variables describing the decision to perform R&D at home
Z_{JV}	Explanatory variables describing the decision to form a joint venturs
Z_{BUY}	Explanatory variables describing the decision to buy R&D from a Sothern firm
Φ	Coefficients
q_{JV}	Probability for forming a joint venture
IPR	Intellectual property rights

Introduction

Intellectual property rights (IPRs) protection is the subject of heated debate in international policy negotiations. Many developing countries feel that the Trade-Related Aspects of Intellectual Property (TRIPs) agreement signed in the Uruguay Round benefits rich countries at the expense of the poor. A major argument in favor of tighter IPRs has been that they encourage innovation from which all the regions of the world benefit. However, a number of countries do not find this argument convincing. The counterargument has been that tighter intellectual property rights only strengthen the monopoly power of large companies that are based in industrial countries, to the detriment of the less developed countries.

One of the developing countries which enforced weak IPRs until 2005 is India. My research interests are related to the development of the Indian pharmaceutical market based on a very important domestic policy: the passage of the Patents Act (1970). Pharmaceutical products (along with other products like food and agrochemicals) became unpatentable and the lifespan of patents for pharmaceutical processes was reduced to 5 years. Between 1970 and 1995 India maintained this weak patent protection system that fostered growth of the domestic pharmaceutical industry and decreased the presence of multinationals. According to Saranga and Phani (2005), the pharmaceutical industry in India was based on reverse-engineering of existing drugs developed by the multinational companies (MNC). Indian firms directed most of their R&D expenditures in that direction. A smaller part of R&D efforts was used to develop existing formulations such that the final product will be similar but not identical with the existing patented drugs. By signing the Agreement on Trade-Related Aspects of Intellectual Property Rights in 1995, India agreed to strengthen its protection of intellectual property by

2005. How would this policy change affect the Indian pharmaceutical market? I answer this question in the first essay by conducting a theoretical and empirical analysis.

In my first essay I employ the Grossman and Helpman (1991b) variety model to study the effect of stronger IPR protection on innovation and imitation in India. Previous theoretical studies analyzing the effects of strengthening Intellectual Property Rights in developing countries discuss the changes in steady-state equilibrium following such a policy change. My first contribution is to derive the impact of stronger IPRs in the transition dynamics of variables between steady-states. Analyzing this dynamic model, I find that in the short run stronger Southern IPR protection promotes innovation and discourages imitation. Both innovation and imitation fall, however, in the long run (steady state). Second, I analyze the impact of the strengthening of IPRs when there is an announcement that the policy will change prior to it being implemented. I show that following the announcement, innovation jumps but not as much as in previous situation, and then it keeps increasing until the time of the policy change when it slowly starts to decrease to the new steady state. Imitation decreases after the announcement, but less than before, and it continues to decrease until it approaches its new lower steady state level. In the case of an announcement, both innovation and imitation approach their new steady-states faster.

I test the above theoretical predictions using firm-level data and a fixed-effects estimation technique. To the best of my knowledge, this is the first such test of the Grossman and Helpman (1991b) dynamic model. I use a panel of 354 Indian pharmaceutical firms over the period 1989 to 2008. This firm level dataset is combined with two patent datasets in order to create the necessary measures for testing the dynamic model. The results suggest that innovation increases faster after the announcement and it continues to increase, though at a slower rate, even after the new intellectual property rights policy is in place. On the other hand imitation exhibits an unexpected increase after the announcement and it decreases after the policy change. R&D offshoring follows a similar path with innovation. This unexpected increase in imitation is the result of Indian firms taking advantage of the time left under the old IPRs regime.

Based on the work of Grossman and Helpman (1991a and 1991b) and the other authors who employed their models, one would expect a swift shift in the rates of innovation and imitation to the new steady state after the policy change. The empirical results presented in my first essay suggest a smoother transition. The transition to the new steady state can be a slow process and even though the policymakers in India might prefer the new steady state to the initial situation, the transition to the new steady state might have an initial negative impact on the Indian economy. The task of the second essay is to have a closer look at the transitional dynamics of imposing stronger intellectual property rights. In this essay I find a few important relationships between exogenous changes in the parameter of the model and the transition path to the new steady state. For example, a larger developed country requires a longer time to reach the new steady state if imitation is endogenous when compared to the case with exogenous imitation. The opposite is true when we are talking about a larger developing country. Given that the economy is a dynamic system, the second essay has yielded some interesting results with respect to the short-run effects of a change in the intellectual property rights. Many existing studies compromise such analysis by only drawing conclusions about the long-run effects (the steady states), whereas this dynamic analysis enables us to determine both the short-run and the long-run effects.

The pharmaceutical industry provides an interesting example regarding the importance that IPR protection has in this sector and the changes that took place in the last twenty years in terms of IPR protection across the world. As mentioned before, in 1995 signatories to the TRIPs agreement agreed to grant product patents by 2005 for pharmaceutical innovations as a condition of membership in WTO. Since 2005, firms from signatory countries have not been able to sell reverse engineered (copied) products. Their business model was affected by the new IPR laws and the firms in the pharmaceutical industry had to adapt to a new environment. To mention a few successful stories, Ranbaxy of India has purchased production facilities in seven foreign countries (China, Ireland, Malaysia, Nigeria, Romania, U.S.A. and Vietnam). In

South Africa, it formed a subsidiary with a local firm (Adcock Ingram) to promote sales of their products on the local market. This is a very common strategy for Indian firms to speed up market approvals and improve customer acceptance of their products. Cipla of India formed joint ventures with Eli Lilly (to sell products in U.S.), Novopharm (to sell products in Canada) and Enaleni Pharmaceuticals Limited (to sell products in South Africa). Lupin of India collaborates with Merck Generics (to sell products in U.K.) and McGaw Inc. (to sell products in U.S.). Collaboration between local firms and multinational companies is not limited to production or marketing. Recent collaboration was targeted towards research and development of new products. For example, Ranbaxy has a global alliance with GlaxoSmithKline Plc. regarding research and development activities and with Eli Lilly regarding clinical trials of drugs.

The "make-or-buy" decision is fundamental to industrial organization, but the concept applies to international trade too. Making a new finished product requires a firm not only to do research and design the goods, but it also necessitates the production or sourcing of its components. For each one of these activities a producer must decide whether to undertake the activity in-house or to purchase the input or service from another firm that may be located abroad. In my third essay I analyze the offshoring decision of companies for either forming a joint venture with a local firm, or entering a contractual partnership, with a special focus on the research and development (R&D) activity. The theoretical model I present underlines three important factors in this decision: the level of intellectual-property-rights protection in the destination country, the wage differential between the two countries and the fixed cost associated with a joint venture. Weak IPRs in the destination country support a joint venture partnership to reduce the risk of knowledge leakage while large fixed costs of establishing a joint venture supports a contractual partnership. I test the implications of the model in the pharmaceutical market for a panel of 89 countries over the period 1990 to 2009 with a binomial logit estimation.

The estimations presented in the third essay show that international intellectual property rights protection is a significant factor for companies to consider when engaging in international partnerships. When companies find themselves in an environment with less secure intellectual property rights protection, they tend to choose joint ventures rather than contractual partnerships. The wage gap between countries and the cost of doing business have a negative effect on the preference for international joint ventures and the fixed costs of establishing a joint venture act as a deterrent to forming a joint venture, as expected. The R&D activity has a significant influence over the organizational structure of offshoring. Firms engaging in R&D offshoring have a greater incentive to form joint ventures than firms offshoring other activities. This can be due to property rights concerns related to leakage of information in countries with weak IPR protection, or it might be the case that firms choose to form joint venture in order to take advantage of transfer pricing opportunities in countries with less taxation.

Chapter 1

IPRs, Innovation, Imitation and Offshoring: The Case of the Indian Pharmaceutical Industry

1.1 Introduction

India has a strong pharmaceutical industry historically built upon the ”process patent” protection of intellectual property rights. A ”process patent” allowed an Indian firm to produce a good invented by someone else as long as it developed a different production process than the original innovator. In 1995, the agreement on Trade Related Aspects of Intellectual Property Rights (hereafter TRIPs) required its signatories, including India, to grant ”product patents” by 2005 for pharmaceutical innovations as a condition of membership in the World Trade Organization (WTO). This policy change strengthened intellectual property rights and was predicted to have significant effects on innovation, imitation and offshoring. Stronger intellectual property rights (hereafter IPRs) protection should encourage innovation and foreign direct investment (hereafter FDI), as well as discourage imitation[1]. In this paper I study these effects based on India's experience.

A theoretical literature has emerged to address the question of the effects of imposing stronger intellectual property rights in developing countries. Two successful models used in

[1] According to the results presented by Lai (1998).

analyzing these effects are the endogenous product cycle models developed by Grossman and Helpman. Grossman and Helpman (1991a) is a quality ladder model (where innovations are higher quality levels), and Grossman and Helpman (1991b) is a product-variety model (where innovations are new varieties). Previous authors who employed the above-mentioned theoretical models to analyze the effects of stronger IPRs on both developed and developing countries were more interested in determining the rate of imitation and innovation in the steady state equilibrium rather than investigating the stability properties of the equilibrium and the transition to the new equilibrium. An exception is Helpman (1993) who employs a simpler model with endogenous innovation but exogenous imitation. He shows that a decrease in the exogenous rate of imitation (stronger IPRs) increases innovation in the short-run but decreases innovation in the long run (the long-run equilibrium is a saddle point).

The Indian example demands that we examine the path of adjustment to the new steady state, as well as changes in the steady-states, since it is unlikely to observe the new steady state only a few years after the actual change in IPRs policy [2]. My theoretical contribution is two-fold. First I derive the impact of stronger IPRs in the transition dynamics of innovation and imitation between steady-states. I employ the model of Grossman and Helpman (1991b) to study the effect of stronger IPRs on innovation and imitation. Analyzing this dynamic model, I find that in the short run stronger Southern IPR protection promotes innovation and discourages imitation. Both innovation and imitation fall, however, in the long run (steady state). Second, I analyze the impact of the strengthening of IPRs when there is an announcement that the policy will change prior to it being implemented. I show that following the announcement, innovation jumps but not as much as in previous situation, and then it keeps increasing until the time of the policy change when it slowly starts to decrease to the new steady state. Imitation decreases after the announcement, but less than before, and it continues to decrease until it approaches its new lower steady state level. In the case with an announcement, both innovation and imitation approach their new steady-states faster.

I test the above theoretical predictions using firm-level data and a fixed-effects estimation

[2] According to Sahoo (2006), it can take between 13 - 20 years for a drug to be developed, tested in clinical trials and be ready for mass production.

technique. To the best of my knowledge, this is the first such test of the Grossman and Helpman (1991b) dynamic model. I use a panel of 354 Indian pharmaceutical firms over the period 1989 to 2008. This firm level dataset is combined with two patent datasets in order to create the necessary measures for testing the dynamic model. Employing a fixed effects estimation procedure I find that innovation follows the adjustment path predicted by the theoretical model while imitation increased. This increase in imitation may be the result of Indian firms taking advantage of the time left under the old IPRs regime.

In the next section I present a review of the literature. Section 1.3 gives some background information about the Indian market. Section 1.4 presents the theoretical models. Section 1.5 presents the data. Section 1.6 reviews the statistical findings and Section 1.7 concludes.

1.2 Literature review

The theoretical literature on product cycle models has seen a revival in recent years. This literature is based on the seminal work of Vernon (1966). He presents a model where new products are first introduced in high income countries, then exported to other high income countries. Eventually production shifts to low income countries, and finally the original product may be exported back to the high income country which first introduced it. Yet while Vernon's original vision of the product cycle assigns a central role to foreign direct investment (FDI), most of the new models capturing his ideas use imitation as the channel of international technology transfer from an innovating region (the North) to an imitating region (the South).

Grossman and Helpman (1991b) follow the 'product cycle' idea that the North is the only source of innovation (new varieties of products), and the only way the South can acquire technology is through 'technology transfer' (imitation) from the North. They study the determinants of the steady state rates of innovation and imitation (both are endogenously determined). An increase in labor supply in the South or a decrease in the labor requirement for imitation generates an increase in the steady-state rates of imitation and innovation. Grossman and Helpman (1991a) developed a similar model where innovations consist of improving one quality of an existing good (the quality ladder model). An increase in the Southern labor force raises imitation. Innovation in the North may rise or fall. In these models new products are being invented by Northern firms and later directly imitated by Southern firms. In the Vernon cycle, Northern firms move production to the South by forming subsidiaries there before imitation shifts ownership but not location of production.

IPR reforms were not explicitly discussed in the above mentioned papers. To analyze the debate between North and South about the enforcement of stronger IPRs in the South, Helpman (1993) employs a simplified version of the Grossman and Helpman (1991b) model with exogenous imitation. His main contribution is his analysis of the transition dynamics between steady states following strengthened IPRs in the South (modeled as a decrease in the exogenous imitation intensity). He finds that stronger IPRs initially raise the rate of innovation, but then it subsequently declines. This and subsequent extensions to Grossman and Helpman models are summarized in Table 1.1.

Lai (1998) modifies the Grossman and Helpman (1991b) model to consider the effects of imitation targeting multinational production. He considers two possible channels of production transfers between the North and the South: FDI and imitation. The effects of stronger IPRs in the South (modeled as a decrease in the exogenous imitation intensity) depend on the channel of production transfer. In the case of technology transfer through imitation (without FDI), stronger IPRs lower the rate of innovation. The effects are opposite if the transfer channel is FDI, or if both transfer channels coexist and the rate of FDI is large. If the technology transfer is made through FDI, Southern firms can imitate only after Northern firms transfer production to the South. Northern firms move production to the South in order to take advantage of lower relative labor costs. In this case the effect of stronger IPRs does not affect the demand for Northern labor as production is entirely in the South. Thus, innovation will rise while its cost remains constant.

Glass and Saggi (2002) question the results of Lai (1998) where stronger Southern IPR protection encourages FDI and innovation. They employ a quality-ladder model and argue that stronger Southern IPR protection reduces the aggregate rate of innovation and the flow of FDI regardless of whether FDI or imitation targeting Northern production serves as the primary channel of international technology transfers. In their model, stronger IPR protection increases the cost of imitation. Glass and Saggi (2002) conclude that the reason for the difference in their results relative to Lai (1998) appears to be the difference in how IPRs protection is modeled (as an increase in the cost of imitation rather than as an exogenous decrease in the imitation intensity). But there is another important difference between the two models: the type of innovation (creating new varieties versus quality upgrading). Contrary to Lai (1998), Glass and Wu (2003) employ a model based on the quality-ladder model developed by Grossman and Helpman (1991a) where imitation is exogenous. They find that stronger IPRs in the South (a decrease in the imitation intensity) decrease FDI and innovation, an opposite result to the one found by Lai . They conclude that stronger IPRs protection may shift the composition of innovation away from improvements in existing products toward development of new products.

The newest extension to the Grossman and Helpman (1991b) model is provided by Branstetter, Fisman, Foley and Saggi (2007). They analyze theoretically and empirically the effects of strengthening IPRs in developing countries in a product variety model with endogenous innovation, imitation, and FDI. The model predicts that IPR reform in the South leads to increased FDI in the North, an increased global rate of innovation and a reduced rate of imitation. Empirically they analyze responses of U.S.-based multinationals and domestic industrial production to IPR reforms in the 1980s and 1990s. They find that there is an overall expansion of industrial activity after IPR reform, suggesting that the expansion of multinational activity more than offsets any decline in the imitative activity of indigenous firms.

My research extends the work of Grossman and Helpman (1991b) and Helpman (1993) by considering the effects of stronger IPRs in the South (modeled as an increase in the cost of imitation) on the adjustment paths between the steady-state rates of innovation and imitation when both innovation and imitation are endogenous. Empirically, I define measures for innovation, imitation and R&D offshoring and I estimate their adjustment following an announced change in the IPRs regime.

Table 1.1: Summary of the Extensions to Grossman and Helpman

	Nature of innovation	Stronger IPR	Results		
			FDI	Innovation	
				W/FDI	W/O FDI
Helpman (1993)	Exogenous w/FDI	Imitation intensity ↓	↑	-	↓
Lai (1996)	New varieties	Imitation intensity ↓	↑	↑	↓
Glass and Saggi (2002)	Higher qualities	Imitation cost ↑	↓	↓	↓
Glass and Wu (2003)	Higher qualities	Imitation intensity ↓	↓	↓	↓
Branstetter et al. (2007)	New varieties	Imitation cost ↑	↑	↑	-

It is difficult to find good proxies for innovation and imitation. Connolly (2003) quantifies spillovers from high technology imports to domestic imitation and innovation in both developed and developing countries. She then considers the contribution of foreign and domestic innovation to real per capita GDP growth. Using data for 75 countries from 1965 to 1990 to create proxies for imitation and innovation, Connolly finds that in conjunction with transportation and communication infrastructure, quality-adjusted R&D, foreign direct investment, and high technology imports positively affect both domestic imitation and innovation. She also finds that IPRs are positively correlated with both innovation and imitation.

One of the first empirical studies regarding the enforcement of product patents for pharmaceuticals under the TRIPs agreement belongs to Chaudhuri, Goldberg, and Jia (2003). They estimate the effects of global patent protection on pharmaceutical products (for the anti-bacterial category fluoroquinolones) in India. They calculate welfare effects using estimated parameters from retail pharmaceutical audits performed by an Indian market research firm. Their study not only estimates the losses from monopoly pricing, but also calculates the potential losses from a reduction in product variety as domestic producers of generic drugs disappear.

A firm-level study on R&D expenditure before and after TRIPs is presented by Dutta and Sharma (2008). They use panel data on Indian firms from 1989 to 2005 to ascertain whether the IPRs reforms were successful in increasing innovation by firms in India. They find strong evidence that Indian firms in more innovation-intensive industries increased their R&D expenditure after TRIPs. They also find that patenting by India in the U.S. increased after TRIPs, and to a greater extent in more innovation-intensive industries.

In order to provide a better understanding of the general transformation of India's economic structure following the implementation of economic reforms, Alfaro and Chari (2009) study the evolution of industrial concentration, the number, and size of firms across ownership types and industries. By employing a firm-level dataset covering the period 1988 - 2005 they find an economy dominated by state-owned firms and traditional private firms (firms incorporated before 1985) with the exception of the service sector. Alfaro and Chari conclude that this situation suggests insufficient reform. Privatization efforts were abandoned after a short spell in the early 2000s and sectors such as manufacturing and financial services remain largely under state control.

Kyle and McGahan (2009) examine the relationship between patent protection for pharmaceuticals and investment in new treatments for neglected diseases that disproportionately affect developing countries. They use a negative binomial regression to examine R&D effort in the form of the number of new clinical trials over time, at the disease level and across countries. They relate R&D effort with measures of disease prevalence, availability of substitute products, dummy variables for neglected diseases, markets with IPRs in place, country level of income, and year fixed effects. Kyle and McGahan (2009) find that the introduction of patent protection (in response to TRIPs agreement) is associated with decreased R&D effort in the developing and least-developed countries.

I start the empirical part of my paper by describing the evolution of domestic and foreign firms in the Indian Pharmaceutical Market between 1989 and 2008 in a manner similar to Alfaro and Chari (2009). Then I define measures for innovation, imitation and R&D offshoring and I estimate their adjustment following an announced change in the IPRs regime. My measures of innovation and imitation are similar to the ones used by Connolly (2003). By using these measures I find that both innovation and imitation increase after TRIPs. Dutta and Sharma

(2008) find similar results in innovation-intensive industries by analyzing the R&D effort of Indian firms. My paper builds upon the work of Dutta and Sharma by measuring the results of the R&D effort and separating these results into innovation and imitation. In contrast with the previous results, Kyle and McGahan (2009) find a decreased R&D effort in the developing and least-developed countries but they only consider investment in treatments for neglected diseases.

1.3 The Indian pharmaceutical market as a test case

Lanjouw (1997) pointed out that the general opinion among developing countries regarding the enforcement of stronger IPRs (or the creation of a patent system, in some cases) is that it will reduce the well-being of these countries. The effects of such a change will affect countries differently, based on their initial conditions. In countries where the domestic industry prospered due to government protection (weak IPRs or tariffs) losses are expected to be larger. This explains why India was reluctant to grant product-patent protection for pharmaceutical products.

In 1973 the Indian government enacted the Foreign Exchange Regulation Act to reduce foreign ownership in domestic industries: less than 40% equity could be held by foreign firms (individual consideration was given to firms in areas requiring sophisticated technology and export oriented industries where foreign ownership could go up to 75%). This measure produced important changes in the ownership structure of the pharmaceutical industry.[3]

In 1993 the Indian government allowed 51% equity stakes to be held by foreign companies. This led foreign firms, which had initially reduced their equity stakes to 40%, to increase their equity stakes. An example is Glaxo Group which in 1983 reduced its equity in Glaxo India from 75% to 40%. In 1993 it raised its equity from 40% to 51%. Other policies intended to foster domestic production were: restrictions on the importation of finished formulations, high tariffs, price controls and ratio requirements (imports of bulk drugs had to be matched by domestic purchases at a given ratio). These policies favored domestic pharmaceutical firms

[3]These facts are drawn from Smith (2002).

and lowered the interest of multinational companies in the Indian market.

A very important policy intended to develop the domestic industry was the passage of the Patents Act (1970). Pharmaceutical products (along with other products like food and agrochemicals) became unpatentable and the lifespan of patents for pharmaceutical processes was reduced to 5 years. Between 1970 and 1995 India maintained this weak patent protection system that fostered growth of the domestic pharmaceutical industry and decreased the presence of multinationals. According to Saranga and Phani (2005), the pharmaceutical industry in India was based on reverse-engineering of existing drugs developed by the multinational companies (MNC). Indian firms directed most of their R&D expenditures in that direction. A smaller part of R&D efforts was used to develop existing formulations such that the final product will be similar but not identical with the existing patented drugs. Very few Indian firms (only big companies, some in cooperation with foreign companies) allocated R&D expenditures towards innovating new drugs. This last activity requires more R&D effort and the uncertainty of success is higher, relative to the other two. Indian firms were able to sell copied products not only on the domestic market but also in other developing countries that had weak patent laws. Being able to manufacture and sell (to the domestic market and other developing countries like the former Soviet Union and Africa) drugs patented by multinational companies before the patents expired allowed Indian firms to move quickly into the world market once the patents expired. India proved to be one of the most prolific imitators, building a strong pharmaceutical industry and becoming an important competitor to MNCs.

In 1995, signatories to the TRIPs agreement including India agreed as a condition of membership in WTO to grant product patents by 2005 for pharmaceutical innovations. Since 2005, Indian firms have not been able to sell reverse-engineered (copied) products. Their activity is limited to developing new products and manufacturing off-patent products or bulk products. Indian firms were already important players on the bulk drug and off-patent drug markets. They expand their reach towards other markets by purchasing plants outside India or by forming joint-venture with local foreign firms. [4] For example, Ranbaxy has purchased production

[4]These facts are drawn from Smith (2002).

facilities in seven foreign countries (China, Ireland, Malaysia, Nigeria, Romania, U.S.A. and Vietnam). In South Africa, it formed a subsidiary with a local firm (Adcock Ingram) to promote sales of their products on the local market. This is a very common strategy for Indian firms to speed up market approvals and improve customer acceptance of their products. Cipla formed joint ventures with Eli Lilly (to sell products in U.S.), Novopharm (to sell products in Canada) and Enaleni Pharmaceuticals Limited (to sell products in South Africa). Lupin collaborates with Merck Generics (to sell products in U.K.) and McGaw Inc. (to sell products in U.S.). Collaboration between Indian firms and multinational companies is not limited to production or marketing. Recent collaboration was targeted towards research and development of new products. For example, Ranbaxy has a global alliance with GlaxoSmithKline Plc. regarding research and development activities and with Eli Lilly regarding clinical trials of drugs. Smith (2002) opines that forcing Indian firms (pharmaceutical or otherwise) to compete with the best international firms and products in India (after IPR harmonization) will encourage them to seek MNC status themselves, and to compete outside India. This approach will bring the Indian firms as significant actors and competitors on the global industrial stage.

A change in the legal basis of patents in India will generate changes in the local pharmaceutical market depending on the degree of patents enforcement. A good measure for the enforcement level would have been data on court rulings in cases of patent infringement in India. Unfortunately these data are not available. However, The Technology Information, Forecasting and Assessment Council (India) provides firm-level data regarding the number of patents notified for opposition until 2004. In Figure C.12 I present the number of patent applications notified for opposition for the 354 Indian pharmaceutical firms in my sample. To compare the changes in the pharmaceutical industry with the overall changes in all Indian industries I present the number of patent applications notified for opposition for all industries in Figure C.13.

Imposing stronger IPRs in India might not affect local sales as most of the drugs sold there are off-patent drugs and the Indian government can still implement price controls[5]. Also, it

[5]For example, in 2005 the National Pharmaceutical Pricing Authority listed ceiling prices for 72 formulations and non-ceiling prices (fixed prices) for 120 formulations. In 2008, 73 ceiling prices and 38 non-ceiling prices

will not affect the exports of off-patent products. For the on-patent drugs, some part will be produced in India (through licensing or offshoring) while the other part will be replaced by imports.[6] But manufacturing is not the only sector that is affected by stronger IPRs. An important characteristic of the pharmaceutical industry is that this industry has very high R&D costs. By imposing a strong IPR regime, India creates a better environment for foreign firms to outsource R&D activities to India. Domestic innovative activity will also be affected. According to Smith (2002) Indian firms are aware that in order to be successful in the long run they should increase their R&D and allocate these efforts towards the development of new formulas. For example, in 1995, Dr. Reddy's Group filed its first two product patent applications for new anti-cancer and anti-diabetes formulations. Cooperative R&D activities were developed between Indian firms and multinational companies before India decided to implement stronger IPRs. How did the 1995 decision influence these collaborations? I answer this question in the following analysis.

1.4 Theoretical considerations

This section is divided into three subsections. In section 1.4.1 the base model developed by Grossman and Helpman (1991b) is described. In addition to the steady-state analysis presented in their paper, I describe the transition dynamics between steady states. In section 1.4.2 I discuss how the transition dynamics change if an announcement about a future policy change (stronger IPRs in the South) is made before the policy is actually implemented.

1.4.1 The Base Model

Grossman and Helpman (1991b) present a dynamic general equilibrium model of two regions, North and South. Innovation takes place in the North while the South imitates technologies that have been invented in the North. The North introduces new products at a rate $g = \dot{n}/n$, where n equals the number (measure) of products society knows how to produce and $\dot{n}$ is

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were listed for formulations.

[6] Sampath (2008), p.21-24

the first derivative of n with respect to time [7]. The South imitates products developed in the North at rate $m = \dot{n}_S/n_N$, where n_S represents the number of products that the South produces while n_N represents the number of products that the South has not yet imitated. The total number of products society knows to produce is $n_S + n_N = n$. Stronger IPRs are modeled as an increase in the labor requirement coefficient for imitation.

Consumers

Preferences are identical in the two regions and a representative consumer has additively separable intertemporal preferences given by lifetime utility

$$U = \int_t^{\infty} e^{-\rho t} \log u(t) \mathrm{d}t \tag{1.1}$$

where ρ is the subjective discount rate.

The instantaneous utility $u(t)$ is given by

$$u(t) = \left[\int_0^n x(j,t)^{\alpha} \mathrm{d}j \right]^{1/\alpha}, \quad 0 < \alpha < 1, \tag{1.2}$$

where $\mathrm{x}(j,t)$ represents consumption of product j at time t.

$$\mathrm{x}(j,t) = p(j,t)^{-\varepsilon} \cdot \frac{E(t)}{P(t)^{1-\varepsilon}}, \quad \varepsilon = \frac{1}{1-\alpha} > 1, \tag{1.3}$$

where $E(t)$ represents aggregate spending on consumer goods at time t, ε the elasticity of demand, and $P(t)$ is a price index at time t such that:

$$P(t) = \left[\int_0^n p(j,t)^{1-\varepsilon} \mathrm{d}j \right]^{\frac{1}{1-\varepsilon}} \tag{1.4}$$

Consumers maximize welfare subject to an intertemporal budget constraint. They choose a rate of growth of consumption spending that matches the difference between the interest rate

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[7] Throughout, dot notation will be used for time derivatives.

and their subjective rate of time preference:

$$\dot{E}(t)/E(t) = r(t) - \rho \tag{1.5}$$

where $r(t)$ is the interest rate.

From this point on without loss of generality I suppress the time index for all variables.

Research and Development (R&D)

The GH(1991b) model features endogenous and costly R&D. Resources devoted to R&D generate two sorts of outputs. First, the innovator/imitator develops a blueprint for production of a particular variety. Second, the R&D activity creates a by-product benefit in the form of general knowledge that contributes to the productivity of later R&D efforts. The stock of industrial knowledge is specific to the country in which the knowledge was created. The stock of knowledge capital in a region is assumed to be proportional to the economy's cumulative research experience measured by the number of product designs available in each region.

The cost of R&D is wa/n, where a is the unit labor requirement, w is the wage and n is the number of products (for each region). As mentioned before, the above formulation assumes that the cost of R&D falls with the number of products society knows how to produce. The process of innovation and imitation are similar, but they have different resource requirements: a_N is the unit labor requirement for a Northern firm performing innovation and $(1+k)a_S$ the unit labor requirement for Southern imitation.[8]

If investment in R&D takes place, the expected reward from this activity, which consists of a blueprint whose value we denote by v_N, must cover R&D costs. The free-entry condition into R&D requires that the equilibrium value of a blueprint cannot exceed R&D costs. If the value of a blueprint falls short of R&D costs, however, no firm invests in R&D. It follows that in an equilibrium with positive innovation R&D costs just equal the present value of a blueprint.

[8] k is a parameter that measures IPR protection intensity. It takes values between 0 and 1, with 0 describing no IPR protection

Given the above specified R&D technology, this condition becomes:

$$v_N = w_N \mathrm{a}_N / n \tag{1.6}$$

where w_N is the Northern wage, a_N in the unit labor requirement for innovation and n is the number of products society knows how to produce.

The free-entry condition for Southern R&D (imitation) is:

$$v_S = w_S(1+k)\mathrm{a}_S / n_S \tag{1.7}$$

where w_S is the Southern wage, $(1+k)\mathrm{a}_S$ in the unit labor requirement for imitation and n_S is the number of products the South knows how to produce.

Now assume that the developed region has well-functioning financial markets, including a stock market. Then the value of a firm (a blueprint) equals the present value of its expected stream of profits. In fact, the only risk faced by a firm is that its product will be imitated by the South. In a time interval of length dt the South imitates a proportion mdt of Northern products. Arbitrage in asset markets implies:

$$\pi_N / v_N + \dot{v}_N / v_N = r + m \tag{1.8}$$

where π_N represents instantaneous Northern profits, r stands for the interest rate and m is the rate of imitation.

For the South, the no-arbitrage conditions in asset markets imply:

$$\pi_S / v_S + \dot{v}_S / v_S = r \tag{1.9}$$

where π_S represents instantaneous Southern profits.

Producers

Goods are manufactured with one unit of labor per unit of output in both regions. A Northern manufacturer that invents a product can charge a monopoly price as long as its product has not been imitated. Given the demand functions, the monopoly price of every product that has not been imitated equals:

$$p_N = \frac{w_N}{\alpha} \tag{1.10}$$

where w_N represents the wage rate in the North and equals the manufacturer's marginal cost.

A Northern firm makes sales x_N and has a marginal cost w_N. The instantaneous profits for these firms are:

$$\pi_N = \left(\frac{1}{\alpha}w_N - w_N\right)x_N = \left(\frac{1}{\alpha} - 1\right)w_N x_N = (1-\alpha)p_N x_N \tag{1.11}$$

A Southern manufacturer that imitates a Northern product can charge a monopoly price

$$p_S = \frac{w_S}{\alpha} \tag{1.12}$$

where w_S is the wage rate in the South.

A Southern firm makes sales x_S and has a marginal cost w_S. The instantaneous profits for these firms are:

$$\pi_S = \left(\frac{1}{\alpha}w_S - w_S\right)x_S = \left(\frac{1}{\alpha} - 1\right)w_S x_S = (1-\alpha)p_S x_S \tag{1.13}$$

The resource market (market clearing conditions)

We can express the labor market clearing conditions by:

$$\mathrm{a}_N \frac{\dot{n}}{n} + n_N x_N = L_N \tag{1.14}$$

for Northern companies and

$$(1+k)\mathrm{a}_S \frac{\dot{n}_S}{n_S} + n_S x_S = L_S \tag{1.15}$$

for Southern companies.

The first term on the left-hand side represents employment in R&D while the second term represents employment in manufacturing.

Dynamics

Let the fraction of goods that have not been imitated be $\zeta = n_N/n$. Starting with the balanced trade condition, I differentiate it and substitute in for the Northern sales as given by the Northern labor constraint (1.14), prices (1.10), wages (1.6) and the definition of innovation. Then I find a second expression, the ratio of profits to the value of the blueprint, by using equations (1.6), (1.11), (1.14) and the definitions of innovation and the fraction of Northern products to total products. Combining these two expressions with equation (1.5) allows us to find equation (1.17). A similar process is performed for the Southern firms to find equation (1.18). By differentiating the fraction of Northern products to total products and using the definitions for innovation and imitation I find equation (1.16). Equations (1.16), (1.17) and (1.18) are the three differential equations that describe the equilibrium. In these equations g and m are jump variables while ζ is a state variable.

$$\dot{\zeta} = g - (g+m)\zeta \tag{1.16}$$

$$\dot{g} = (L_N/\mathrm{a}_N - g)\left[\rho + m + g - (1/\alpha - 1)(L_N/\mathrm{a}_N - g)/\zeta\right] \tag{1.17}$$

$$\begin{aligned}\dot{m} = \frac{1-\zeta}{\zeta}\left[\rho + m\frac{\zeta}{1-\zeta} - \frac{1-\alpha}{\alpha}\frac{1}{(1+k)\mathrm{a}_S}\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)\right]\cdot \\ \cdot\frac{1}{(1+k)\mathrm{a}_S}\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right) - \frac{m}{(1-\zeta)\zeta}\left[g - (m+g)\zeta\right]\end{aligned} \tag{1.18}$$

In Appendix A, I present the calculations that led to the above differential equations.

The following numerical example will show the transitional dynamics following the imposition of stronger IPRs. Set the unit labor requirement in innovation to $\mathrm{a}_N = 9$ and imitation $\mathrm{a}_S = 8.5$, and the discount rate to $\rho = .2$. Set Northern labor supply $L_N = 10$ and Southern labor supply $L_S = 11$. The initial IPRs parameter is $k = 0.05$ which will increase to 0.1 when stronger IPRs are imposed therefore, the labor requirement coefficient $(1+k)\mathrm{a}_S$ increases with stronger IPRs.

Following the imposition of stronger IPRs, innovation first jumps up and then slowly decreases to its new lower steady state. Imitation initially jumps down and it decreases at diminishing rate until it reaches its new steady state value. The number of Northern products increases slowly after the imposition of stronger IPR. These adjustments are presented in Figures C.1-C.3.

There are two counteracting effects of enforcing stronger IPRs in the South. First, it lowers the rate of imitation and prolongs the expected duration of monopoly of each Northern innovator. This raises the returns to innovation. Second, since firms produce longer in North, it raises the demand for Northern labor and Northern wage, and hence raises the cost of innovation. Due to this the profits from innovation decreases. As shown by the previous example, the the second effect dominates the first one in the long run, and the rate of innovation declines in steady state.

1.4.2 Introducing an Initial Announcement (before the actual policy change)

Previous authors did not consider a policy change announcement before the implementation. Given the market I am analyzing (the Indian Pharmaceutical Market), I am interested in seeing how Indian firms reacted to the 1995 TRIPS Agreement (when India joined WTO and agreed to implement stronger IPRs starting in 2005). In section 1.6 I will add to the timeline below the important years for the Indian Market.

The timing of the model is as follows:

Figure 1.1: General Timeline for the Initial Announcement

0 t_0 t_1 t_2 t

The economy begins in the original steady state at time 0. At time t_0 firms in the economy realize (following an announcement made by the Southern authorities) that stronger intellectual property rights will be in effect in the South at a future date t_1. If the firms disregard the announcement, they will remain at the initial steady state until the IPRs will actually change (and the analysis will be similar with the one in the previous section). However, developing the new skills required in an economy with stronger IPRs (imitation R&D being different from innovation R&D) takes time and it might require different assets so firms will react immediately to the announcement. Following the announcement, innovation jumps but not as much as in previous section, and then it keeps increasing until the time of the policy change when it slowly starts to decrease to the new steady state. Imitation also jumps less than before and it continues to decrease slower and slower until it reaches the new steady state value. The number of Northern products increases slowly after the imposition of stronger IPRs. I present the transitional dynamics with and without an announcement in Figure C.1-C.3. In the case with no announcement, the endogenous variables approach the steady-state values slower.

A special situation arises when the Southern government doesn't enforce the existing IPRs laws between the time of the announcement and the time when stronger IPRs are implemented. In this case both innovation and imitation decrease after the announcement but then they increase above the initial steady state level before the policy change. This period of lawlessness when the Southern government doesn't enforce an IPRs system that is about to become obsolete can explain the increase in imitation following the announcement that I find later on in the data.

1.5 Data

In order to test the conclusions of the theoretical model, in this section I look at the determinants of innovation, imitation and R&D offshoring evolution in 354 Indian pharmaceutical firms over the period 1989 to 2008. This section provides a general overview of the data, along with measures for innovation, imitation and R&D offshoring.

The data set used in the paper is from the Center for Monitoring the Indian Economy (CMIE) database. The firm level data constitute an unbalanced panel covering the period 1989-2008. The sample consists of 354 firms. This dataset provides information like: company information (e.g., name, products, ownership), income and expenditure statement, liabilities and assets.

The previous data set is appended with firm-level information regarding the number of Indian and European patents filed in each year. This information was collected from the

Technology Information, Forecasting and Assessment Council (India) and the European Patent Office.

Definitions for the variables used in the estimations are presented at the end of the paper in Table B.1. In what follows I will take a closer look at the main variables.

A recent paper by Alfaro and Chari (2009) analyzes the evolution of firm size, market share and industry concentration over time in industries that were liberalized. For a better understanding of the industry dynamics I present similar statistics for the Indian pharmaceutical market at the end of my paper in tables B.3- B.11.

The columns in Table B.1 present data on the average number of firms by type of ownership. For the full sample the number of firms grew relative to the beginning of the sample period. But this growth is not reflected in both types of ownership. The number of foreign firms increased in 1995 - 2000 to 33 from 23 in 1989 - 1994. But this trend didn't last as the number of foreign firms decreased in 2001 - 2004 to 26 and it reached 17 in 2005 - 2008. On the other hand domestic firms steadily increased their number in the Indian pharmaceutical market. The increase in average number of foreign firms after 1995 can be the result of a positive signal towards the implementation of stronger intellectual rights and the liberalization of foreign direct investment. However, over the period 2001 - 2004 the number of both foreign and domestic firms begins to decline. As the deadline for stronger IPRs implementation approached, pharmaceutical firms consolidated their market position by acquiring/merging with other firms and other firms exited the market as their future profits were affected by the new laws.

Table B.4 presents information on average assets of ownership type (in constant rupees crore). [9] Average assets have grown across the entire period for both types of ownership. The table shows high accumulation of assets in domestic and foreign firms between 2001 - 2004 and 2005 - 2008.

Table B.5 presents information on sales (in constant rupees crore). The period 1995 - 2000 shows an unexpected decrease in average total sales for both types of ownership. This is a

[9] 1 crore = 10 million rupees.

period when small firms are active in the market. In contrast, the 2005 - 2008 period presents substantial growth in average total sales.

Table B.6 shows profits (Net Profits) by ownership. Foreign firms exhibit a sustained growth across years while domestic firms face a temporary decrease in average profits between 1995 and 2000.

Table B.7 reflects the return on assets. In the period 1995 - 2000 both types of firms exhibit a decline in the return of assets. However, in the next period foreign firms face an increase in the return on assets while the return to domestic firms keeps declining. Between 2005 - 2008 both domestic and foreign firms have higher returns on assets, but Indian private firms experience a larger relative change.

Tables B.8 - B.11 describes the composition of number of firms, assets, sales and profitability as a percentage of the total (by ownership group). Between 1989-1994 domestic firms accounted for 88% of the total number of firms while foreign firms accounted accounted for 12%. Over time, the percentage of foreign firms keeps decreasing. The share of total assets accounted by foreign firms between 1989-1994 is 19%, the remaining 81% being held by domestic firms. Similar with the number of firms, the share of total assets accounted for by foreign firms keeps decreasing. The share of total sales accounted for by foreign firms increases to 27% between 1995 - 2000 from an initial level of 25%. After 2001, the share of total sales held by foreign firms sees a significant drop. The most striking change is represented by the share of total net profits accounted by foreign firms which doubles its value between 1995-2000 only to be reduced by half in the next period (2001 - 2004). Domestic firms are more dynamic between 2001 - 2004 and 2005 - 2008 and they seem to dominate the Indian market in terms of number, size (total assets and sales) and profits.

1.5.1 Innovation, imitation and R&D offshoring

Descriptive statistics for these variables (for the full sample or separated between foreign and domestic firms) are presented in Figures C.4-C.9.

Innovation

Innovation represents the development of new products. The proxy for innovation is the number of patents a firm filed in Europe in a certain year. This is considered to be the "successful" fraction of R&D expenditures. Some Indian firms might not consider the European Union as a target market for the near future and might not apply for EU patents. This would lead to an underestimate of the innovation measure for the Indian firms.[10] In Figure C.4 the total number of EU patents follows an ascending path until 2006 when it starts decreasing. But the behavior of foreign and Indian (domestic) firms is very different. Indian firms do not acquire EU patents before 1995, and after that you can notice a steady increase in EU patents. This is presented in Figure C.5.

Imitation

Imitation is the duplication (by manufacturing) of products developed by other firms. The proxy for imitation is the difference between the number of Indian patents and the number of EU patents within a year. If the difference is negative then imitation is considered to be zero.[11] This difference is presented in Figure C.6. Based on this figure there is an increase in imitation in 1995 followed by a decrease after 2003. Looking at the disaggregated graph in Figure C.7 we can see that most of the variation in the variable of interest comes from the domestic firms.

R&D offshoring

R&D offshoring is an R&D process (innovation) subcontracted to domestic firms in a foreign country. It is difficult to find a good measure for R&D offshoring. In this paper I am going to use revenue from exported services as a proxy for R&D offshoring. Beside the R&D offshoring

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[10] Connolly (2003) quantifies spillovers from high technology imports to domestic imitation and innovation. An important feature of her paper is that she attempts to distinguish between innovative and imitative activities. She measures innovation as the number of U.S. patents granted to residents of a given country each year, by the date of application, as reported by the U.S. Patent and Trademark Office. This measure is similar to my measure of innovation.

[11] Connolly (2003) measures imitation as the number of applications for domestic patents by home residents, as reported by the World Intellectual Property Organization, minus U.S. patent applications by residents of the same country. This is based on the idea that imitating firms will patent the products in their home countries but will not apply for a patent in U.S.. There are drawbacks to this measure as a firm might not intend to sell its products in U.S. (this overestimates imitative activities) or an imitative firm might not bother to get domestic patent protection if IPR are weak (this underestimates imitative activities). This measure is similar to my measure of imitation.

activity, this measure will include revenues from clinical trials offshoring along with revenues from other services. The clinical trials are not related to the IPR regime. Their inclusion will reduce the effect of an IPR change on the R&D offshoring measure.[12] In Figure C.8, the years 2000 and 2006 exhibit jumps in the amount of services exported. According to Figure C.9, the 2000 increase in services exported is based on domestic firms while the 2006 increase relies on both domestic and foreign firms.

1.5.2 Other firm-level-variables (firm experience, assets and wages) and industry-level-variables (relative price and interest rate)

Experience

The year 1989 is considered the starting point for firms that were already in the market (it is not possible to distinguish between firms that entered the market in 1989 and firms that were already on the market). For the first year in the market (1990 for firms that were on the market in 1989) a firm gets one point experience. For each additional year they get another point. This proxy is intended to reflect familiarity with the market and research experience.

The individual wage is computed as the ratio of salaries and wages expenses to the number of employees. Theory suggests that an increase in either innovation or imitation in India, should put upward pressure on wages.

Relative price

This measures how Northern prices are moving relative to the Indian price. An increase in the price of pharmaceuticals in the North (where there are strong IPRs) relative to the price of pharmaceuticals in the South, should provide an increased incentive for Indian firms to innovate. Imitated products can not be sold in those markets.

Interest rate

[12] Feenstra and Hanson (1996) define offshoring as the share of imported intermediate inputs in the total purchase of non-energy materials. Hijzen et al. (2004) calculate the ratio of imported inputs to the value added of an industry (same measure is employed by Feenstra and Hanson in 1999). Hummels et al. (2001) introduce a measure that takes account only of those imported intermediates which are used to produce an exported good. Extrapolating these to measure R&D offshoring in this paper would be difficult as I do not have information about "Northern" firms.

Higher interest rates should reduce the incentive to innovate (a process that requires a significant higher financial effort compared with imitation) and shift interest towards imitation.

1.6 Descriptive statistics and estimations

The timeline for the data I use is as follows:

Figure 1.2: Timeline with the Doha Ministerial Declaration

0	t_0		t_1		t_2	t
1989	1995	2001	2005	2008	?	
I	II	III	IV			

The economy begins in the original steady state at time 0. In my dataset the origin corresponds to the year 1989. In 1995 (t_0), the TRIPs (Trade Related aspects of Intellectual Property Rights) ended with an agreement in which the developing countries were required to grant product patents (by 2005) for pharmaceutical innovations as a condition of membership in World Trade Organization (WTO). An announcement was made at this point about a future policy change (with a 10 year delay). In November 2001 the Doha Ministerial Declaration on TRIPS and Public Health clarified some details regarding the implementation of stronger IPRs starting in 2005. This was an important announcement and I will take it into consideration when I model the dynamic transition. In 2005, stronger IPRs are implemented in India and in 2008 my dataset ends.

1.6.1 The equations

In this section I look at information about some of the variables employed in the theoretical model. Changes in the measures for innovation, imitation and R&D offshoring can come from four sources: time specific effects that reflects industry or macro-level changes (X_t), observed differences in plant characteristics (Y_{it}), changes in IPR will be reflected by changes in dummy variables (Z_t) and random noise (ϵ_{it}).

Using the fixed-effects method I will estimate the following equations:

$$G_{it} = \alpha X_t + \beta Y_{it} + \gamma Z_t + \epsilon_{it} \tag{1.19}$$

$$M_{it} = \alpha X_t + \beta Y_{it} + \gamma Z_t + \epsilon_{it} \tag{1.20}$$

$$O_{it} = \alpha X_t + \beta Y_{it} + \gamma Z_t + \epsilon_{it} \tag{1.21}$$

where:

1. G_{it} is innovation, M_{it} is imitation and O_{it} is offshoring;

2. X_t includes:

   - Relative price, one year lag (rel_pricelag)

   - Interest rate, one year lag (rlag)

3. Y_{it} includes wages, total assets, experience in the industry;

   - "individual wages$_{it}$"

   - "R&D expenses$_{it}$"

   - "Total exports$_{it}$"

   - "Total assets$_{it}$"

   - "experience$_{it}$"

   - dummy variable for foreign ownership$_{it}$

4. Z_t includes dummy variables that split the time frame 1989 - 2008 into four intervals;

   - 1989 - 1994 (dataset begins - TRIPS Agreement)

   - 1995 - 2000 (TRIPS Agreement)

   - 2001 - 2004 (Doha Ministerial Declaration on TRIPS, clarifies some conditions of the TRIPS agreement)

   - 2005 - 2008 (IPR changes - end of dataset)

5. noise;

The equations doesn't take into consideration some firm-specific effects.

$\epsilon_{it} = \mu_i + \nu_{it}$

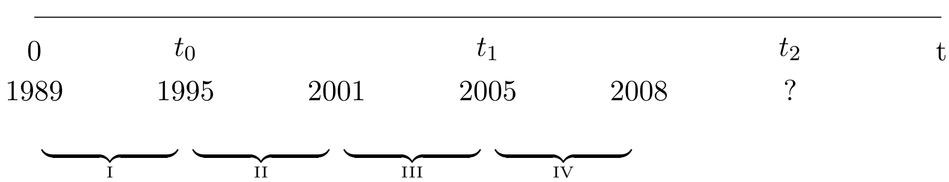
Where μ_i is a time invariant unobservable firm effect (independently distributed across firms) which might be correlated with the explanatory variables and ν_{it} is the part of the error term uncorrelated with the explanatory variables.

The same equations will be tested in loglinear form, where except for dummy variables, all other variables (dependent or independent) will be in natural logarithms. The estimation results for these equations will be presented in Table B.12 where the loglinear equations will be numbered (19'), (20') and (21').

1.6.2 Groups of year - specific fixed effects

The time frame is split into four intervals and the dummy variables we considered have the same coefficient within each interval. The choice of intervals will be 1989 - 94, 1995 - 00, 2001 - 04 and 2005 - 08. The cut-off points are 1995 (when India joined WTO and agreed to comply with the TRIPS condition), 2001 (Doha Ministerial Declaration on TRIPS and Public Health clarified the application of "compulsory licensing") and 2005 (when IPRs legislation was changed in India).

Figure 1.3: Timeline explaining the four time intervals used in estimations



Innovation

The results for the fixed effects estimation for innovation (measured as the number of EU patent applications within a year) are presented in Table B.12. For the 1995 - 2000 interval the coefficients show a significant (at 95% level) increase in innovation (relative to the 1989 - 1994 period), followed by a slower growth in the intervals 2001 - 2004 and 2005 - 2008. This is an expected increase in innovation following the imposition of stronger IPRs in India. A strengthening of Southern IPR protection makes imitation less attractive and increases the rate of offshoring freeing up resources in the North for innovation. The coefficient for the relative price is also significant at the 95% level. Higher Northern prices provide a higher incentive for innovation. A higher markup might make it profitable for Indian firms to develop new products and acquire monopoly power on the Northern markets. The coefficient on the interest rate has an unexpected sign, but it is not significant. Higher interest rates should provide a lower incentive for innovation. Developing new products is an expensive activity and it requires resources to support it. If the interest rate is too high one would expect the Indian firms to forego expensive plans (for example, developing new products) in favor of cheaper ones (manufacturing soon to go off - patent drugs). The relationship between individual wages and innovation is positive and significant at the 95% level. In the theoretical model everybody gets the same wage in the South. However one would expect innovating firms to reward their employees better than imitative firms as the potential to sell original products is bigger (they can also export them in developed countries). An increase in Southern individual wages should make imitation less profitable and increase the incentive to innovate in the South. Although the sign of the coefficient for the individual wages is as expected (and the coefficient is also significant at the 95% level), the magnitude of the coefficient is too big. One possible explanation for this is that the individual wage is much smaller than any other variables included in the estimation. Being an exporter has a negative influence on innovation (significant at the 95% level). One would expect only Indian innovators to be able to export their products but this is not true. Many Indian firms export their products in other developing countries where IPR protection is weak, or they export soon to go off - patent drugs and bulk drugs to the North. Experience is positively correlated with the explanatory variable and significant. The assets and R&D skills in this market are concentrated in the hands of incumbents (either private or foreign firms). Having foreign ownership also provides a base for innovation. Foreign subsidiaries benefit from the assistance of their parent company. The number of observations is 4254 and the adjusted R-squared for this estimation is .9004. One possible reason for such a high value is the high number of dummy variables (one for each company).

When using the loglinear specification, some of the coefficients change sign. The individual wage remains significant and it has a big effect on innovation. Total exports are significant and become positive. A 1 percent increase in total exports will increase innovation by .08 percent. A 1 percent increase in total R&D increases innovation by .34 percent. Experience changes signs and a 1 percent increase in experience decreases innovation by .06 percent. Foreign ownership fosters innovation.

Imitation

The results for the fixed-effects estimation for imitation are presented in Table B.12. The coefficients for the year dummies are positive except in 2005 - 2008 which is negative as expected (and significant). Implementing the TRIPS Agreement in 2005 resulted in lower imitation. It turns out that imitation increased between 1995 and 2000, following the policy change announcement, and it increased less within the next period of time (2001 - 2004). A possible reason for the increase in imitation after the announcement is that new imitators might have entered the market to take advantage of the time left before the policy is implemented. Also, Southern imitating firms have developed a set of skills that might not be adapted easily to innovation. Until Southern firms manage to reeducate their workers they will continue to do what they now how to do. The coefficient for relative prices became negative (and still significant), as expected. Higher relative prices discourage imitation (shift resources towards innovation). The interest rate becomes significant. Higher interest rates discourage innovation and promote imitation. The size of the firm (total assets) is negatively related with the measure for imitation, but the size of the coefficient is small. A higher individual wage in India reduces imitation. The size of the coefficient is big again. R&D expenditure is also positively correlated with imitation (as it was with innovation). R&D expenditure represent the effort while innovation/imitation represent the results. Old incumbents are prolific at both innovation and imitation. Foreign ownership acts as a deterrent to imitation.

As before, when using the loglinear specification some of the coefficients change sign. The coefficients for the year dummies are significant and keep their sign. Relative price negatively influences imitation (decrease by .27 percent). High interest rates discourage innovation and promote imitation. Total R&D and experience are both significant and lead to more imitation. The foreign firm dummy is significant and has a negative sign.

R&D offshoring

R&D offshoring is measured by the services exported. The results for the fixed-effects estimation for R&D offshoring are presented in Table B.12. The coefficients for time dummies show a negative influence on R&D offshoring. This supports the idea that stronger IPR might decrease offshoring. However, none of the coefficients is significant. The relative price has a negative influence of R&D offshoring, but higher prices at home should not deter cost - saving offshoring. The coefficient in front of the relative price is not significant. The interest rate has a positive sign, and the coefficient is significant. Total exports increase the amount of R&D offshoring, and the coefficient is significant at the 95% level. Experience provides a boost to the export services. Foreign firms perform less R&D offshoring than Indian firms (the coefficient is not significant). This would mean that there is less intra-firm offshoring than offshoring at arms length.

In the loglinear specification the time dummies change sign and become significant at the 95% level. This supports the idea that stronger IPR might increase offshoring to India. A 1 percent increase in the interest rate fosters R&D offsoring by .03 percent. Total exports increase offshoring by .1 percent. A 1 percent increase in total assets increases R&D offshoring by .04 percent.

1.6.3 From imitation to innovation

Imitation can be a stepping stone for innovation.[13] The skills acquired by the Indian firms in the process of reverse-engineering Northern products can prove to be an advantage in adapting to the new IPR system. Indian firms can use their R&D experience in order to develop new products and become multinationals. In this section I run a panel data logit (fixed effects) estimation having as dependent variable the firm-level ratio of EU patents to Indian patents. Higher values of this ratio denote higher probability of being an innovator, lower values signal

[13]This statement is drawn from Glass & Saggi (2002).

imitation. Table B.13 presents the impact of firm characteristics on the ratio (EU/Indian) patent applications. Experience and higher interest rates increase the odds of becoming an innovator. On the other, a counterintuitive result says that export activity reduces the odds of becoming an innovator. But this result is not strictly counterintuitive because India exports imitated products to developing markets. As more countries around the globe adopt stronger IPRs, it will be difficult to find an export destination for imitated products and innovation will become a requirement for exports.

Harmonization of IPRs legislation in India relative to the rest of the world and liberalization of trade and capital mobility are bringing Northern and Southern firms closer together in terms of their characteristics. To support this idea Figure C.10 presents the evolution of EU to total patent applications for foreign firms over the years (1989 - 2008). Total patent applications is the summation of EU patents and Indian patents applications. Starting in 1989 we notice the Northern firms had many European patents and very few Indian patents. As time passes we notice a slight movement towards the 45 degree line, where the Northern firm will hold an equal number of EU and Indian patents. But this movement is more obvious for the Indian firms. In Figure C.11 we can observe the evolution of EU and Indian patent applications for domestic firms over the years (1989 - 2008). Before 1994 Indian firms didn't hold any EU patents (or very few). Starting in 1994 we can see a steady increase in the Indian interest towards acquiring European patents. After 2005, the Indian firms are much closer to the 45 degree line than the foreign firms.

Fixed designation of firm's profile

My previous definitions of innovation and imitation allow a firm to switch its designation from imitator to innovator to imitator again year by year. In the following paragraphs I discuss the possibility of defining a firm as an innovator or imitator for the whole sample. First, I define the variable TOTAL Patents as the summation of all patents (EU and Indian) for each firm for the entire sample. Then, I calculate the ratio of EU Patents to TOTAL Patents for each firm for the entire sample. Firms without patents will receive a missing value for this ratio. Firms that have at least one patent will receive a value between zero and one. Based on the ratio of EU Patents to TOTAL Patents I separate the firms into four categories: "generic producers" (for firms without patents), "imitators" (for firms with a ratio below .1), "switch firms" (imitators with the potential to become innovators; with a ratio between .1 and .8) and innovators (with a ratio above .8). Given this separation there are 221 firms in the first category, 43 firms in the second, 80 in the third and 10 in the last one. In the end I use these categories to determine if the designation of a firm into one of these types influences its decision to innovate or imitate.

The fixed-effects estimation results, including dummy variables for the last three categories defined above, are presented in Table B.14. The inclusion of these dummy variables does not affect too much the coefficients found before. As expected, innovators have the biggest influence on innovation. However, the second biggest influence comes from imitators, not from switch firms. Looking at imitation we can see that the switch firms have the biggest positive influence on imitation, while innovators have a negative impact on imitation. Imitators, switch firms and innovators have a similar influence on offshoring.

Model misspecification with respect to the average wage by firm

The estimations presented in Table B.12 include the variable "individual wage" which reflects both supply and demand conditions in the Indian pharmaceutical market. Given that other variables reflecting the market conditions are included in the estimations the question arises whether or not there is collinearity between the individual wage and the other explanatory variables. To assess the relevance of the individual wage for my estimations, I excluded the variable from the estimations to see whether other variables become significant and I compared the new adjusted R-squared with the old values. The results are presented in Table B.15. When the individual wage is excluded from the estimations the coefficients keep their significance.

1.7 Conclusions

In this essay, I analyzed the transition dynamics of imposing stronger intellectual rights in a model with endogenous innovation and imitation based on Grossman and Helpman (1991b). Previous authors who employed the Grossman and Helpman model in order to analyze the effects of stronger IPRs were more interested in determining the rate of imitation and innovation in the steady state equilibrium without investigating the transition to a new equilibrium. My first contribution is to derive the theoretical transition dynamics for the Grossman and Helpman model (1991b). Innovation increases in the short run, while in the long-run stronger IPRs will reduce innovations. Imitation falls in the short run and keeps decreasing slowly until it reaches the new steady state. Given the nature of the market I study, my second contribution is to analyze the situation when the Southern government announces its intentions prior to the policy implementation of stronger IPRs. Following the announcement of imposing stronger IPR in the South, innovation increases (jumps) but not as much as when there is no announcement, and then it keeps increasing until the time of the policy change when it slowly starts to decrease to the new steady state. Imitation decreases (jumps) less than before and it continues to decrease at a diminishing rate until it reaches the new steady state value. In the case with announcement, the endogenous variables approach the new steady-states faster.

On the empirical side I employ a rich firm-level panel data of 354 Indian pharmaceutical firms over the period 1989 to 2008. Combining this dataset with Indian and EU patent data allows me to analyze the predictions based on the theoretical model. Following the empirical estimation I find that innovation follows the adjustment path predicted by the theoretical model while imitation follows an opposite adjustment (India's announcement regarding the TRIPS agreement resulted in an increase in imitation). This unexpected increase in imitation may be the result of Indian firms trying to take advantage of the time left under the old IPR regime. This can be explained in the theoretical model as a temporary slackening in IPRs enforcement. To model this situation I can reduce the labor coefficient for imitation in the theoretical model between the years 1995 and 2005.

According to the Pharmaceutical Drug Manufacturer Association there were approximately 20,000 registered drug manufacturers in India in 2005. These manufacturers sold 9 billion dollars worth of formulations and bulk drugs. 85% of these formulations were sold in India while over 60% of the bulk drugs were exported, mostly to the United States and Russia. Most of the firms in the market are small-to-medium companies; 250 of the largest companies control 70% of the Indian market. Following the 1970 Patent Act, multinationals represent only 35% of the market, down from 70% thirty five years ago. My sample has data on the 354 major Indian pharmaceutical firms out of a total of 20,000. These 354 companies are either traded on India's major stock exchanges or they represent the central public sector companies. According to the Pharmaceutical Drug Manufacturer Association the rest of the Indian pharmaceutical firms account for approximately 30% of the Indian market. Without measuring the patenting activity of these firms (either Indian patents, EU patents or no patents) my measures of innovation and/or imitation are understated.

Following the 1970 Patent Act the number of multinationals present in the Indian market decreased. However the trend should have changed in 2005 when stronger IPR were implemented in India. Looking at table B.3. we notice that the number of foreign firms continued to decrease after 2005. A possible explanation comes from the refusal of some foreign firms to provide information to the Center for Monitoring the Indian Economy(CMIE). Foreign firms, as opposed to their Indian counterparts, are not required by law to report information to CMIE.

Following the theoretical model, my empirical estimations analyze the effect of stronger IPR on innovation and imitation. However the empirical work is not limited to innovation and imitation. I am also interested on how stronger IPR regimes in developing countries influence the R&D offshoring decision to those countries. When I defined my R&D offshoring variable I used revenue from exported services as my proxy for R&D offshoring. Beside the R&D offshoring activity, this measure will include revenues from clinical trials offshoring along with revenues from other services. The clinical trials are not related to the IPR regime. Their inclusion will reduce the effect of an IPR change on the R&D offshoring measure. My future work will include finding a stronger measure for R&D offshoring. A second change will affect my measure for experience. I will replace experience with firm age. The dataset includes information regarding the year of incorporation for each firm. I will use this information to create my "age" measure. To investigate if the variable age has a non-linear influence on innovation/imitation I will include the "age squared" variable. The Central Bank of India maintains a dataset on new firms that can be used to verify whether or not my sample is representative.

From a spatial point of view, the innovative firms in India are clustered around seven centers: Delhi, Kolkata, Mumbai, Pune, Hyderabad, Bangalore, and Cennai. One of the factors that led to concentration of pharmaceutical firms in these clusters is the positive externality created by each innovative firm. My next step is to gather information about the spatial distribution of non-innovative firms and see if they are clustered more that innovative firms. Do non-innovative firms cluster around other cities? Can we find dynamic formation of new clusters as Indian firms move from imitation to innovation? This information will shed light on the role of spatial externalities as a source of economic growth.

Chapter 2

The Transitional Dynamics of Innovation and Imitation Following the Imposition of Stronger Intellectual Property Rights in Developing Countries

2.1 Introduction

Intellectual property rights (IPR) protection is the subject of heated debate in international policy negotiations. Many developing countries feel that the Trade-Related Aspects of Intellectual Property (TRIPs) agreement signed in the Uruguay Round benefits rich countries at the expense of the poor. A major argument in favor of tighter IPRs has been that they encourage innovation from which all the regions of the world benefit. A number of countries do not find this argument convincing, however. The counter argument has been that tighter intellectual property rights only strengthen the monopoly power of large companies that are based in industrial countries, to the detriment of the less developed countries.[1]

Stronger IPR protection is claimed to encourage not only innovation but also foreign direct investment, and to discourage imitation. Based on this idea, developing countries need to

[1] According to the discussion presented by Branstetter et al. (2007).

have stronger IPR protection to attract foreign direct investment.[2] But what are the effects of imposing stronger intellectual property rights in developing countries? Are the short-run effects different from the long-run effects?

A literature has emerged to address the question of the effects of imposing stronger intellectual property rights in developing countries. Two of the models used in analyzing these effects are the endogenous product cycles models developed by Grossman and Helpman. Grossman and Helpman (1991a) is a quality ladder model (when innovations are higher quality levels), and Grossman and Helpman (1991b) is a product-variety model (when innovations are new varieties).

These models developed by Grossman and Helpman (1991a and 1991b) are based on the influential idea of Vernon (1966) regarding the international product cycle. A developed group of countries, called the North, first invents new products and supplies them in the international market. The developing countries, called the South, follow up through imitation and gradually specialize in the production of these goods over time. Explaining product cycles is important for understanding the effects of stronger IPRs in developed and developing countries. These two models look at how innovation and imitation respond to changes in policy. They provide a framework for undertaking a wide range of extensions, such as introducing tariff policies, migration, stronger intellectual property rights, etc. However, the models are highly complicated and so the effects of alternative policies are typically derived only in the steady state. Evaluating the effects of policies requires to account for the transition to a new steady state. Grossman and Helpman assumed the existence of a steady state equilibrium of the global economy and did not analyze the stability properties of that equilibrium or the transitional dynamics in their papers.

Lai (1998), Glass and Saggi (2002) and Glass and Wu (2007) are some of the authors who employed the above-mentioned models in order to analyze the effects of stronger IPRs on both developed and developing countries (in terms of innovation, foreign direct investment and imitation). These authors were more interested in determining the rate of imitation

[2] Argument presented by Lai (1998).

and innovation in the steady state equilibrium without investigating the transition to a new equilibrium. An exception from this rule is made by Helpman (1993) who employs a simpler model with endogenous innovation but exogenous imitation. He shows that a decrease in the exogenous rate of imitation (stronger IPRs) increases innovation in the short-run and decreases innovation in the long run.

The task of the present essay is to explain transitional dynamics of imposing stronger intellectual property rights in these two types of endogenous product-cycle models: when innovations are new varieties and when innovations are higher quality levels. In order to analyze the short-run and long-run effects of stronger IPRs I start with a simpler case of endogenous innovation and exogenous imitation (for both new varieties and higher quality levels). Then, I analyze the more complex case when both innovation and imitation are endogenous (for both cases). I find a few important relationships between exogenous changes in the parameter of the model and the transition path to the new steady state. The larger the Northern labor force, the longer the time necessary to reach the new steady state in the case with endogenous imitation (but the shorter the time in the case with exogenous imitation). The opposite is true for larger Southern labor force and the transition to the new steady state becomes longer. Looking at the unit labor requirement in innovation we can say that for larger value the recovery time will be shorter when imitation is endogenous (but the opposite is true in the case with exogenous imitation). Increasing the labor requirement in imitation will prolong the transition. Changes in the subjective discount rate generate the biggest variations in the return and recovery times.

An important contribution of this essay is a full characterization of the dynamic path of the economy. I not only investigate the steady state equilibrium, I verify that the steady state in the economy is a saddle point. Given that the economy is a dynamic system, the paper has yielded some results with respect to the short-run effects of a change in the intellectual property rights. Many existing studies compromise such analysis by only drawing conclusions about the long-run effects (the steady states), whereas this dynamic analysis enables us to determine both the short-run and the long-run effects.

Why are transitional dynamics important? In 1995, the TRIPs (Trade Related aspects of Intellectual Property Rights) ended with an agreement in which the developing countries were required to grant product patents (by 2005) for pharmaceutical innovations as a condition of membership in World Trade Organization (WTO). At that time around fifty developing countries were not granting product patent protection for pharmaceutical products. India was one of these countries that agreed with this requirement. Before that India was granting patents based on the production process. This allowed imitation from the domestic Indian firms of the products introduced to the market by multinational corporations (MNC).[3] India proved to be one of the most prolific imitators, building a strong pharmaceutical industry and becoming an important competitor to multinational corporations. Indian pharmaceutical industry development relied upon reverse engineering of patented products, and Indian firms directed most of their R&D expenditures in that direction. Very few Indian firms (big companies, some in cooperation with foreign companies) allocated R&D expenditures towards innovating new drugs. This last activity requires more R&D effort and the uncertainty of success is higher, when compared with reverse engineering. After 2005, Indian firms were not able to sell reverse-engineered products (developed after 2005).[4] What changes should we expect in the Indian pharmaceutical market? Most of the literature is interested in determining the rate of imitation and innovation in the steady state equilibrium (before and after the policy change). But the economy doesn't adjust immediately to the new steady state. The transition can be a slow process and even though the policymakers in India might prefer the new steady state to the initial situation, the transition to the new steady state can have a negative impact on the Indian economy. In my first essay ("IPRs, Innovation, Imitation and Offshoring: The Case of the Indian Pharmaceutical Industry"), using a panel of 354 Indian pharmaceutical firms over the period 1989 to 2008 I present the adjustments of the rates of innovation, imitation following a change in the intellectual property rights policy in India. Based on the work of Grossman and Helpman (1991a and 1991b) and the other authors who employed their models, one would expect a swift shift in the rates of innovation and imitation to the new steady state after the policy change. The empirical results presented in my first essay suggest a smoother

[3]These facts are drawn from Saranga and Phani (2005).

[4]These facts are drawn from Smith (2002).

transition.

The literature review is presented in Section 2.2. Section 2.3 describes the Helpman (1993) paper: the transitional dynamics of stronger IPR in the new variety model with exogenous imitation. The calculations for this section are presented in Appendix D. Section 2.4 analyzes the new variety model with endogenous imitation and the corresponding calculations are presented in Appendix E. Concluding remarks are made in Section 2.5. In order to compare the transition dynamics for the two types of innovation (new varieties versus higher quality levels) I expanded Helpman's (1993) work to the correspondent model of innovations in higher quality levels and exogenous imitation in Appendix F. Appendix G applies the same reasoning for the quality ladder model with endogenous imitation.

2.2 Literature review

This section will provide a general overview of the literature. However, the details encompassed in the models developed by Grossman and Helpman (1991a and 1991b) along with the analysis performed by Helpman (1993) will be presented in the next sections.

Grossman and Helpman (1991b) follow the "product cycle" idea that the North is the only source of innovation of new varieties of products, and the only way the South can acquire technology is through "technology transfer" (imitation) from the North. They study the determinants of the steady state rate of innovation and imitation (both are endogenously determined). An increase in labor supply in the South or a decrease in the labor requirement for imitation generates an increase in the steady-state rates of imitation and innovation. Grossman and Helpman (1991a) developed a similar model where innovations consists of improving one quality of an existing good (the quality ladder model). An increase in the Southern labor force raises imitation. Innovation in the North may rise or fall. In these models new products are being invented by Northern firms and later directly imitated by Southern firms. In the Vernon cycle, Northern firms move production to the South by forming subsidiaries there before imitation shifts ownership but not location of production.

IPR reforms were not explicitly discussed in the above mentioned papers. To analyze the debate between North and South about the enforcement of stronger IPRs in the South, Helpman (1993) employs a simplified version of the Grossman and Helpman (1991b) model with exogenous imitation. His main contribution is his analysis of the transition dynamics between steady states following strengthened IPRs in the South (modeled as a decrease in the exogenous imitation intensity). He finds that stronger IPRs initially raise the rate of innovation, but then it subsequently declines. The next section of the paper will present his findings.

Lai (1998) modifies the Grossman and Helpman (1991b) model to consider the effects of imitation targeting multinational production. He considers two possible channels of production transfers between the North and the South: FDI and imitation. The effects of stronger IPRs in the South (modeled as a decrease in the exogenous imitation intensity) depend on the channel of production transfer. In the case of technology transfer through imitation (without FDI), stronger IPRs lower the rate of innovation. The effects are opposite if the transfer channel is FDI, or if both transfer channels coexist and the rate of FDI is large. If the technology transfer is made through FDI, Southern firms can imitate only after Northern firms transfer production to the South. Northern firms move production to the South in order to take advantage of lower relative labor costs. In this case the effect of stronger IPRs does not affect the demand for Northern labor as production is entirely in the South. Thus, innovation will rise while its cost remains constant.

Glass and Saggi (2002) question the results of Lai (1998) where stronger Southern IPR protection encourage FDI and innovation. They employ a quality-ladder model and argue that stronger Southern IPR protection reduces the aggregate rate of innovation and the flow of FDI regardless of whether FDI or imitation targeting Northern production serves as the primary channel of international technology transfers. In their model, stronger IPR protection increases the cost of imitation. Glass and Saggi (2002) conclude that the reason for the difference in their results relative to Lai (1998) appears to be the difference in how IPRs protection is modeled (as an increase in the cost of imitation rather than as an exogenous decrease in the imitation intensity). But there is another important difference between the two models: the type of innovation (creating new varieties versus quality upgrading). Contrary to Lai (1998), Glass and Wu (2007) employ a model based on the quality-ladder model developed by Grossman and Helpman (1991a) where imitation is exogenous. They find that stronger IPRs in the South (a decrease in the imitation intensity) decrease FDI and innovation, an opposite result to the one found by Lai . They conclude that stronger IPRs protection may shift the composition of innovation away from improvements in existing products toward development of new products.

There are some important differences between the "new varieties" and "quality ladder models". When innovation is targeting new varieties we talk about horizontal product differentiation. In this setup successful innovation enable Northern firms to earn profits until imitation occurs. At that point Northern firms need to develop new products in order to resume earning profits. In the "quality ladder models" there is vertical product differentiation. Successful innovation earns profits for the Northern firms until imitation occurs. Then, Northern firms need to improve on the quality of Southern imitations in order to resume earning profits. Consumers maximize a different instantaneous utility function resulting in different instantaneous demands for goods. In the "new varieties" model firms charge a fixed markup over the marginal cost. In the "quality ladder models" Northern firms set price equal to the quality increment over the marginal cost. As a last difference, in the "new varieties" model the R&D process depends on the cumulative R&D experience in the region. My contribution is to explain transitional dynamics of imposing stronger intellectual property rights in these two types of endogenous product cycles models and to find the conditions that lead to different adjustment paths.

2.3 Helpman (1993) - endogenous innovation (new varieties) and exogenous imitation

In his paper Helpman develops a dynamic general equilibrium model of two regions, North and South. Innovation takes place in the North while the South imitates technologies that have been invented in the North. The model builds on the theory of endogenous growth and international trade that has been developed by Grossman and Helpman (1991b). Its main contribution is the analysis of the transition dynamics between steady states following strengthened IPRs in the South (modeled as a decrease in the exogenous imitation intensity)

The North introduces new products at a rate $g = \dot{n}/n$, where n equals the number (measure) of products society knows how to produce. The South imitates Northern products at the exogenous rate $m = \dot{n}_S/n_N$, where n_S represents the number of products that the South knows how to produce while n_N represents the number of products that the South has not yet imitated. The number of products society knows to produce is $n_S + n_N = n$.

The number of products available at time t can be defined:

$$n(t) = n(0)e^{gt} \tag{2.1}$$

Let the fraction of goods that have not been imitated be $\xi = n_N/n$. Given that $\dot{\xi}/\xi = \dot{n}_N/n_N - \dot{n}/n$, and $\dot{n}_N = \dot{n} - \dot{n}_S$, the following law of motion can be derived:

$$\dot{\xi} = g - (g+m)\xi \tag{2.2}$$

Consumers

A consumer has additively separable intertemporal preferences given by lifetime utility

$$U = \int_t^{\infty} e^{-\rho t} \log u(t)\, \mathrm{d}t \tag{2.3}$$

where ρ is the subjective discount rate and $u(t)$ is the instantaneous utility.

The flow of utility depends on consumption of the above mentioned n products via a constant elasticity of substitution preference structure:

$$u(t) = \left[\int_0^n x(j,t)^{\alpha}\, \mathrm{d}j\right]^{1/\alpha} \ , \ 0 < \alpha < 1 \tag{2.4}$$

where $x(j,t)$ represents consumption of product j at time t.

Consumers allocate spending only across the available products. With homothetic preferences, demand functions can be derived directly from individual preferences:

$$x(j,t) = p(j,t)^{-\varepsilon}\frac{E(t)}{P(t)^{1-\varepsilon}} \quad , \quad \varepsilon = \frac{1}{1-\alpha} > 1 \tag{2.5}$$

where $E(t)$ represents aggregate spending on consumer goods at time t, ε the elasticity of demand, and $P(t)$ a price index at time t such that:

$$P(t) = \left[\int_0^n p(j,t)^{1-\varepsilon}\mathrm{d}j\right]^{1/1-\varepsilon} \tag{2.6}$$

Substituting the demand functions (2.5) into (2.4), and taking account of (2.6), we obtain the indirect utility function:

$$\log u(t) = \log E(t) - \log P(t) \tag{2.7}$$

Consumer maximize welfare subject to an intertemporal budget constrain. They choose a rate of growth of consumption spending that matches the difference between the interest rate and his subjective rate of time preference:

$$\dot{E}(t)/E(t) = r(t) - \rho \tag{2.8}$$

From this point on I suppress the time index for all variables.

Research and Development (R&D)

Innovation is costly, requiring labor input. Let the invention of new products per unit time $\dot{n}$ equal lK_n/a, where a represents a productivity parameter in innovation, l is labor employed in R&D, and K_n is the cumulative stock of knowledge in the inventive activity. Assume that K_n equals n. Therefore the rate of innovation becomes $g = l/\mathrm{a}$.

If investment in R&D takes place, the expected reward from this activity, which consists of a blueprint whose value we denote by v_N, must cover R&D costs. The equilibrium value of a blueprint cannot exceed these costs, because otherwise the demand for labor by innovators becomes unbounded (free entry into innovation). If the value of a blueprint falls short of R&D costs, however, no firm invests in R&D. It follows that in an equilibrium with positive innovation R&D costs just equal the value of a blueprint. Given the above specified R&D technology, this condition becomes

$$E(v_N) = w_N \mathrm{a}/n \tag{2.9}$$

where w_N is the Northern wage.

Now assume that the developed region has well functioning financial markets, including a stock market. Then the value of a firm (a blueprint) equals the present value of its expected stream of profits, because firms face idiosyncratic risks that can be diversified away via portfolio holdings. In fact, the only risk faced by a firm is that its product will be imitated by the South. In a time interval of length dt the South imitates a proportion $m\,\mathrm{d}t$ of northern products. Every product that has not previously been imitated faces the probability $m\,\mathrm{d}t$ of being imitated in the next time interval of length $\mathrm{d}t$. Arbitrage in asset markets implies:

$$\frac{\pi_N}{v_N} + \frac{\dot{v}_N}{v_N} = r + m \tag{2.10}$$

where π_N represents instantaneous profits and r stands for the nominal interest rate. This condition states that the profit rate (the first term on the left-hand side) plus the rate of capital gain on equity holdings equals the risk adjusted (by the probability of being imitated) interest rate.

Producers

Goods are manufactured with one unit of labor per unit output in both regions. A Northern manufacturer that invents a product can charge a monopoly price as long as his product has not been imitated. Given the demand functions (2.5), the monopoly price of every product that has not been imitated equals

$$p_N = \frac{1}{\alpha} w_N \tag{2.11}$$

where w_N represents the wage rate in the North (and equals the manufacturer's marginal cost).

It follows that the n_N products that have not been imitated are priced with a markup above Northern wages. The technology of a product that has been imitated by the South becomes available to all Southern manufacturers. In that event, competition leads to marginal cost pricing of the remaining n_S products:

$$p_S = w_S \tag{2.12}$$

where w_S is the wage rate in the South. It is assumed that the wage is higher in the North. Therefore the price of goods manufactured in the North is also higher. Taking account of the pricing practices (2.11) and (2.12), the price index P from equation (2.6) can be represented by:

$$P = n_N^{1/1-\varepsilon} \cdot \left[\zeta \cdot p_N^{1-\varepsilon} + (1-\zeta) \cdot p_S^{1-\varepsilon}\right]^{1/1-\varepsilon} \tag{2.13}$$

A Northern firm charges a price $p_N = \frac{1}{\alpha} w_N$, makes sales x_N and has a marginal cost w_N. The instantaneous profits for these firms are:

$$\pi_N = \left(\frac{1}{\alpha} w_N - w_N\right) \cdot x_N = \left(\frac{1}{\alpha} - 1\right) \cdot w_N \cdot x_N = (1-\alpha) \cdot p_N \cdot x_N \tag{2.14}$$

The resource market (market clearing conditions)

Define L_i as the labor force of region i, where $i = N, S$. Then we can express the labor market clearing conditions by: In the South:

$$n_S x_S = L_S \tag{2.15}$$

In the North:

$$\mathrm{a}g + n_N x_N = L_N \tag{2.16}$$

where the first term on the left-hand side of (2.16) represents employment in R&D while the second term represents employment in manufacturing.

Using the resource constraint (2.16) it follows from (2.14) that:

$$\pi_N = (1-\alpha)\cdot p_N \cdot \frac{L_N - \mathrm{a}g}{n_N}$$

Substituting this together with (2.11) and (2.9) into (2.10) implies:

$$\frac{1-\alpha}{\alpha}\cdot\frac{L_N - \mathrm{a}g}{\mathrm{a}\zeta} + \frac{\dot{v_N}}{v_N} = r + m \tag{2.17}$$

Assume that there are no financial capital flows between the two regions, so that the North finances investment in R&D entirely with domestic savings. The lack of international capital mobility implies that the trade account is balanced at every point in time:

$$E_N = p_N\, n_N\, x_N$$

Using this relationship together with (2.11) and (2.16),

$$\dot{E}_N = \dot{p}_N\ (L_N - \mathrm{a}g) - \mathrm{a}\, p_N\, \dot{g}$$

$$\frac{\dot{E}_N}{E_N} = -\frac{\mathrm{a}\dot{g}}{L_N - \mathrm{a}g} + \frac{\dot{p}_N}{p_N}$$

From the valuation of firms on the supply side given by (2.9), and the pricing of goods (2.11), the rate of increase in the price of Northern products equals the rate of appreciation of a firm plus the rate of innovation. Substituting this relationship together with the previous equation into (2.8), we obtain an expression for the interest rate:

$$r = \rho + g - \frac{\mathrm{a}\dot{g}}{(L_N - \mathrm{a}g)} + \frac{\dot{v}_N}{v_N} \tag{2.18}$$

From (2.9), (2.17), and (2.8), we obtain a differential equation for the rate of innovation:

$$\dot{g} = (L_N/\mathrm{a} - g)\,[\rho + m + g - (1/\alpha - 1)\,(L_N/\mathrm{a} - g)\,/\zeta] \tag{2.19}$$

Equation (2.19) together with the differential equation (2.2) for the fraction of goods that have not been imitated:

$$\dot{\zeta} = g - (g + m)\zeta \tag{2.2}$$

form an autonomous system of two differential equations in (g, ζ). In this system, ζ is a state variable while g is a jump variable. When $\dot{g} = 0$ equation (2.19) becomes

$$\zeta = (1/\alpha - 1)\left(L_N/\text{a} - g\right)/(\rho + m + g) \tag{2.20}$$

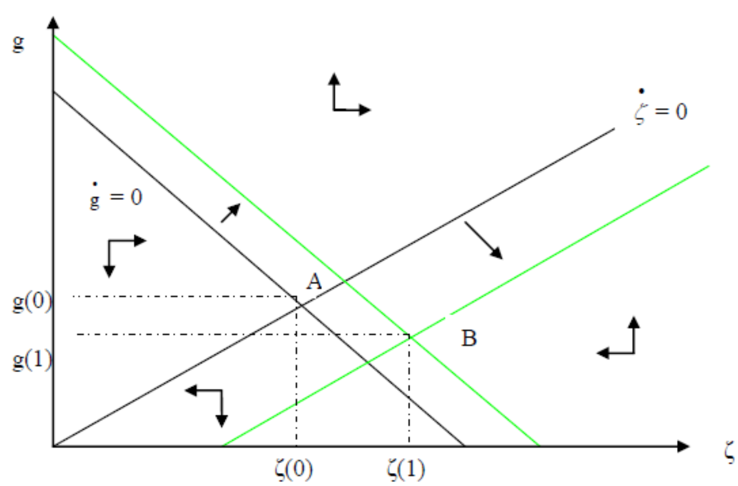
When $\dot{\zeta} = 0$, equation (2.2) becomes:

$$\zeta = \frac{g}{g + m} \tag{2.21}$$

Stronger intellectual property rights are modeled as a decline in the rate of imitation. Let $m = \tilde{m} - \mu$, where the initial value of μ is zero. An increase in μ is the effect of stronger IPRs.

In Figure 2.1 below, the intersection of the two curves described by the equations (2.20) and (2.21) at point A describes the steady-state long-run equilibrium. It follows from (2.20) and (2.21) that a reduction in the rate of imitation shifts both curves $\dot{g} = 0$ and $\dot{\zeta} = 0$ to the right, with the latter shifting by proportionately more. The result is that the long-run equilibrium point shifts down and to the right, implying that the long-run rate of innovation g declines and the long-run fraction of products that have not been imitated ζ increases.

Figure 2.1: Phase diagram for long run equilibrium



A proper evaluation of the effects of tighter IPRs will not focus only on the steady state values (of g and ζ) but also on the entire trajectory of g and ζ. The analysis is restricted to economies that are initially in steady state ($\zeta(0) = \bar{\zeta}$). In this case we can calculate the first order response of (ζ, g) to a tightening of intellectual property rights from a linearized version of the differential equations (2.19) and (2.2) around their steady state values.

More details about the linearized version are provided in appendix D.

Taking into account the initial conditions $\zeta(0) = \bar{\zeta}$ Helpman gets:

$$\frac{d\zeta(t)}{d\mu} = \left(1 - e^{-\lambda t}\right) \frac{d\bar{\zeta}}{d\mu} \tag{2.22}$$

$$\frac{dg(t)}{d\mu} = \frac{d\bar{g}}{d\mu} + \Lambda e^{-\lambda t} \frac{d\bar{\zeta}}{d\mu} \tag{2.23}$$

where λ and Λ are positive. It follows from these equations that the fraction of goods that have not been imitated rises at each point in time following a tightening of IPRs (except for $t = 0$). On the other hand, although the rate of innovation declines in the long run, (2.23) suggests that it may increase in the short run.

Can the rate of innovation rise temporarily as a result of tighter IPRs? The long-run equilibrium point A shifts horizontally to B. The new equilibrium trajectory passes through B and slopes downward. Therefore initially the system jumps from A to A' and subsequently follows the saddle path to B.

$$\frac{d\bar{\zeta}}{d\mu} = \frac{\bar{g}}{\left[m\rho + \frac{1}{\alpha}(m + \bar{g})\right]^2 \alpha}$$

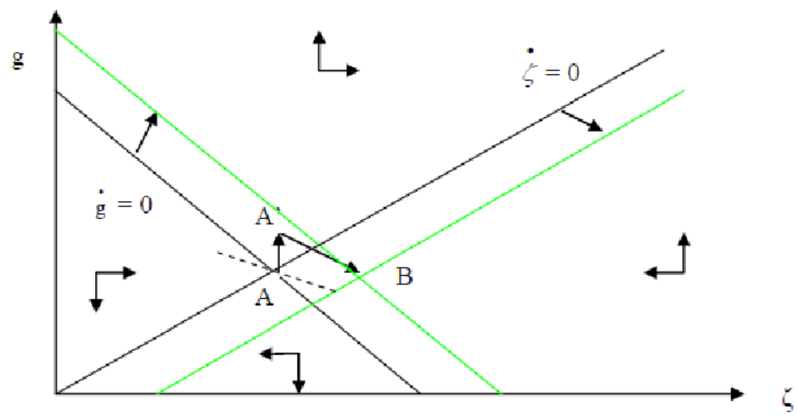
$$\frac{d\bar{g}}{d\mu} = -\frac{\bar{g}\rho}{\left[m\rho + \frac{1}{\alpha}(m + \bar{g})\right]^2}$$

Together with (2.21) these expressions imply:

$$\frac{dg(0)}{d\mu} = \frac{\bar{g}(\Lambda - \alpha\rho)}{\left[m\rho + \frac{1}{\alpha}(m + \bar{g})\right]^2 \alpha} \tag{2.24}$$

It results that the rate of innovation rises on impact. A tightening of intellectual property rights initially raises the rate of innovation, but then the rate of innovation subsequently declines. This movement is presented in Figure 2.2 below.

Figure 2.2: Phase diagram for short run changes



A numerical simulation

To better understand the model described by Helpman (1993) I employ a numerical simulation to see the effects of different parameters on the transition path. The following numerical example will show the transitional dynamics following the imposition of stronger IPR. Set the unit labor requirement in innovation to $a_N = 5$, the discount rate to $r = 0.2$, Northern labor supply $L_N = 10$ and the initial imitation intensity $m = 0.3$ (which will decrease to 0.2 when stronger IPR are imposed).

Figure 2.3: Transition path for the innovation rate when imitation is exogenous

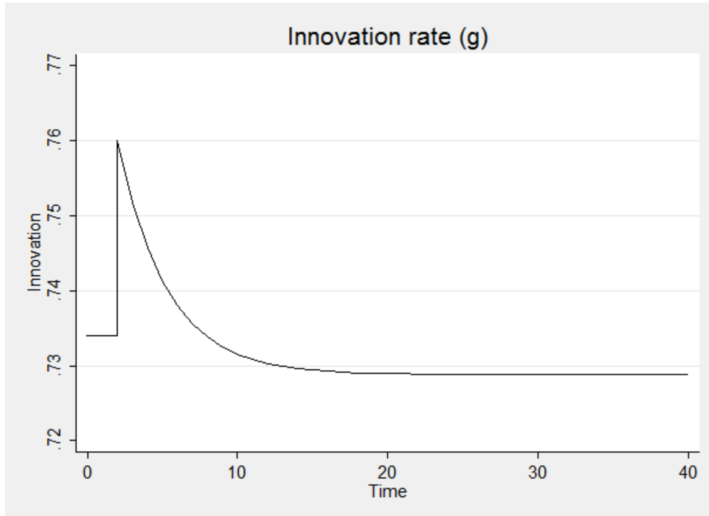
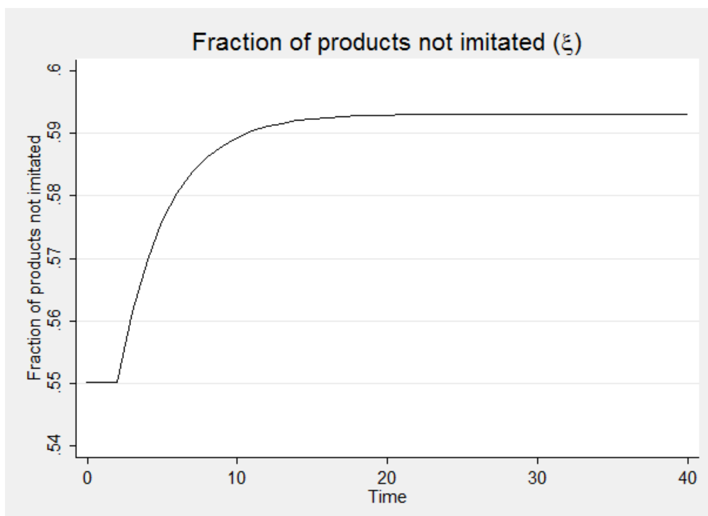


Figure 2.4: Transition path for the fraction of products not imitated when imitation is exogenous



The effects of imposing stronger intellectual property rights on the transition dynamics for the innovation and imitation rates depend on the parameters of the economy in question. The following tables shows how the transition paths are affected: for all cases in the following tables, the initial IPR parameter $k = 0$ will increase to 0.1 when stronger IPR are imposed such that the labor requirement coefficient $(1 + k)\mathrm{a}_S$ increases with stronger IPR. Then I analyze how changes in the Northern labor supply, the unit labor requirement in innovation, and other parameters affect the initial jumps (the jump amplitudes), the time it takes for the rate of

Table 2.1: Changes in Northern labor supply L_N - Exogenous imitation

L_N	a_N	α	ρ	m_0	μ	Jump in g	Return time	Recovery time
0.02	1	0.6	0.2	0.3	0.1	0.000904515	1.75375	14.5841
0.03	1	0.6	0.2	0.3	0.1	0.00134579	1.75854	14.5927
0.04	1	0.6	0.2	0.3	0.1	0.00177988	1.76316	14.5989
0.05	1	0.6	0.2	0.3	0.1	0.00220692	1.76761	14.6027
0.1	1	0.6	0.2	0.3	0.1	0.00424025	1.78746	14.5863
0.15	1	0.6	0.2	0.3	0.1	0.00611439	1.80336	14.5154
0.2	1	0.6	0.2	0.3	0.1	0.00784353	1.81555	14.396
0.25	1	0.6	0.2	0.3	0.1	0.00944111	1.82428	14.235
0.3	1	0.6	0.2	0.3	0.1	0.0109196	1.82985	14.0393
0.35	1	0.6	0.2	0.3	0.1	0.0122902	1.83258	13.8155
0.36	1	0.6	0.2	0.3	0.1	0.0125523	1.83281	13.7679
0.38	1	0.6	0.2	0.3	0.1	0.0130651	1.83298	13.6704
0.4	1	0.6	0.2	0.3	0.1	0.0135633	1.83276	13.5699
0.45	1	0.6	0.2	0.3	0.1	0.0147478	1.8307	13.3079
0.5	1	0.6	0.2	0.3	0.1	0.0158521	1.82666	13.0345
0.55	1	0.6	0.2	0.3	0.1	0.0168832	1.82092	12.7537
0.6	1	0.6	0.2	0.3	0.1	0.0178476	1.8137	12.4691
0.65	1	0.6	0.2	0.3	0.1	0.0187511	1.80522	12.1835
0.68	1	0.6	0.2	0.3	0.1	0.0192661	1.7996	12.0126
0.7	1	0.6	0.2	0.3	0.1	0.0195988	1.79566	11.8992
0.72	1	0.6	0.2	0.3	0.1	0.0199233	1.79158	11.7862
0.75	1	0.6	0.2	0.3	0.1	0.0203953	1.78521	11.618
0.8	1	0.6	0.2	0.3	0.1	0.0208504	1.77857	11.4514
0.85	1	0.6	0.2	0.3	0.1	0.0218509	1.76217	11.0704
0.9	1	0.6	0.2	0.3	0.1	0.022517	1.74983	10.8058
0.95	1	0.6	0.2	0.3	0.1	0.0231461	1.73709	10.5482
2	1	0.6	0.2	0.3	0.1	0.0311333	1.46084	6.74069
4	1	0.6	0.2	0.3	0.1	0.0363877	1.10162	3.8447

innovation to return to the initial value in its way to the new steady state (return time) and the recovery time (the time required to go 99% of the distance between the initial steady state and the new steady state).

Table 2.2: Changes in the unit labor requirement in innovation a_N - Exogenous imitation

L_N	a_N	α	ρ	m_0	μ	Jump in g	Return time	Recovery time
0.7	0.1	0.6	0.2	0.3	0.1	0.0390184	0.81802	2.31515
0.7	0.2	0.6	0.2	0.3	0.1	0.0355616	1.17272	4.31491
0.7	0.3	0.6	0.2	0.3	0.1	0.0325113	1.38511	6.0045
0.7	0.4	0.6	0.2	0.3	0.1	0.0298472	1.52252	7.41024
0.7	0.5	0.6	0.2	0.3	0.1	0.0275283	1.61508	8.56882
0.7	0.6	0.6	0.2	0.3	0.1	0.0255078	1.67904	9.51922
0.7	0.7	0.6	0.2	0.3	0.1	0.0237411	1.72402	10.298
0.7	0.8	0.6	0.2	0.3	0.1	0.0221887	1.75606	10.9373
0.7	0.9	0.6	0.2	0.3	0.1	0.0208172	1.77907	11.4637
0.7	1	0.6	0.2	0.3	0.1	0.0195988	1.79566	11.8992
0.7	1.1	0.6	0.2	0.3	0.1	0.0185104	1.80764	12.2613
0.7	1.2	0.6	0.2	0.3	0.1	0.0175332	1.81626	12.5642
0.7	1.3	0.6	0.2	0.3	0.1	0.0166514	1.82238	12.8189
0.7	1.4	0.6	0.2	0.3	0.1	0.0158521	1.82666	13.0345
0.7	1.5	0.6	0.2	0.3	0.1	0.0151245	1.82956	13.2178
0.7	1.6	0.6	0.2	0.3	0.1	0.0144595	1.83141	13.3746
0.7	1.7	0.6	0.2	0.3	0.1	0.0138496	1.83247	13.5095
0.7	1.8	0.6	0.2	0.3	0.1	0.0132883	1.83293	13.626
0.7	1.85	0.6	0.2	0.3	0.1	0.0130241	1.83298	13.6784
0.7	1.9	0.6	0.2	0.3	0.1	0.0127701	1.83293	13.7272
0.7	2	0.6	0.2	0.3	0.1	0.0122902	1.83258	13.8155
0.7	5	0.6	0.2	0.3	0.1	0.00575161	1.80048	14.5337
0.7	6	0.6	0.2	0.3	0.1	0.00488194	1.79318	14.5685
0.7	15	0.6	0.2	0.3	0.1	0.00206535	1.76615	14.6017
0.7	20	0.6	0.2	0.3	0.1	0.00156373	1.76087	14.5961

Table 2.3: Changes in the subjective discount rate ρ - Exogenous imitation

L_N	a_N	α	ρ	m_0	μ	Jump in g	Return time	Recovery time
0.7	1	0.6	0.01	0.3	0.1	0.0233071	6.38736	11.977
0.7	1	0.6	0.02	0.3	0.1	0.0230907	5.22673	11.9901
0.7	1	0.6	0.03	0.3	0.1	0.0228766	4.56235	12.0012
0.7	1	0.6	0.04	0.3	0.1	0.0226649	4.10053	12.0106
0.7	1	0.6	0.05	0.3	0.1	0.0224555	3.74933	12.018
0.7	1	0.6	0.06	0.3	0.1	0.0222485	3.46783	12.0235
0.7	1	0.6	0.07	0.3	0.1	0.0220438	3.23425	12.0272
0.7	1	0.6	0.08	0.3	0.1	0.0218415	3.0356	12.0289
0.7	1	0.6	0.09	0.3	0.1	0.0216416	2.86351	12.0287
0.7	1	0.6	0.10	0.3	0.1	0.021444	2.71227	12.0265
0.7	1	0.6	0.11	0.3	0.1	0.0212488	2.57783	12.0224
0.7	1	0.6	0.12	0.3	0.1	0.0210561	2.45719	12.0164
0.7	1	0.6	0.13	0.3	0.1	0.0208656	2.34808	12.0084
0.7	1	0.6	0.14	0.3	0.1	0.0206776	2.24874	11.9985
0.7	1	0.6	0.15	0.3	0.1	0.0204919	2.15778	11.9867
0.7	1	0.6	0.16	0.3	0.1	0.0203086	2.07407	11.9729
0.7	1	0.6	0.17	0.3	0.1	0.0201277	1.9967	11.9573
0.7	1	0.6	0.18	0.3	0.1	0.019949	1.92491	11.9398
0.7	1	0.6	0.19	0.3	0.1	0.0197728	1.85808	11.9204
0.7	1	0.6	0.2	0.3	0.1	0.0195988	1.79566	11.8992
0.7	1	0.6	0.21	0.3	0.1	0.0194272	1.73721	11.8761
0.7	1	0.6	0.22	0.3	0.1	0.0192578	1.68233	11.8513
0.7	1	0.6	0.23	0.3	0.1	0.0190907	1.63069	11.8246
0.7	1	0.6	0.25	0.3	0.1	0.0187633	1.53598	11.7662
0.7	1	0.6	0.30	0.3	0.1	0.0179832	1.33915	11.5918
0.7	1	0.6	0.40	0.3	0.1	0.0165777	1.05927	11.1386
0.7	1	0.6	0.42	0.3	0.1	0.0163196	1.01573	11.0345
0.7	1	0.6	0.45	0.3	0.1	0.0159456	0.956177	10.8717
0.7	1	0.6	0.48	0.3	0.1	0.0155868	0.902614	10.7022
0.7	1	0.6	0.5	0.3	0.1	0.0153557	0.869815	10.5861

Table 2.4: Changes in the measure of substitutability α - Exogenous imitation

L_N	a_N	α	ρ	m_0	μ	Jump in g	Return time	Recovery time
0.7	1	0.4	0.2	0.3	0.1	0.0133635	1.5981	10.6699
0.7	1	0.45	0.2	0.3	0.1	0.0150235	1.6502	11.0637
0.7	1	0.5	0.2	0.3	0.1	0.0166322	1.70165	11.4213
0.7	1	0.55	0.2	0.3	0.1	0.0181665	1.7509	11.7132
0.7	1	0.6	0.2	0.3	0.1	0.0195988	1.79566	11.8992
0.7	1	0.62	0.2	0.3	0.1	0.020136	1.81163	11.9325
0.7	1	0.63	0.2	0.3	0.1	0.0203957	1.81908	11.9386
0.7	1	0.65	0.2	0.3	0.1	0.0208958	1.83272	11.9267
0.7	1	0.67	0.2	0.3	0.1	0.0213676	1.8444	11.8793
0.7	1	0.69	0.2	0.3	0.1	0.0218077	1.85376	11.7917
0.7	1	0.7	0.2	0.3	0.1	0.0220146	1.85743	11.7314
0.7	1	0.75	0.2	0.3	0.1	0.0228938	1.86323	11.2406
0.7	1	0.8	0.2	0.3	0.1	0.0234336	1.84046	10.3802
0.7	1	0.82	0.2	0.3	0.1	0.0235175	1.82026	9.91705
0.7	1	0.85	0.2	0.3	0.1	0.0234471	1.77407	9.08227
0.7	1	0.88	0.2	0.3	0.1	0.0230517	1.70294	8.06701
0.7	1	0.9	0.2	0.3	0.1	0.0225273	1.63676	7.28104
0.7	1	0.92	0.2	0.3	0.1	0.0216972	1.5499	6.39754
0.7	1	0.95	0.2	0.3	0.1	0.019507	1.35982	4.84731
0.7	1	0.98	0.2	0.3	0.1	0.0146914	1.01405	2.84352

These calculations confirm a few important relationships. When the size of the Northern labor force is larger, the time necessary to reach the new steady state is shorter. Looking at the unit labor requirement in innovation we can say that an increase in this value will decrease the recovery time. Increasing the labor requirement in imitation will prolong the transition. Changes in the subjective discount rate generate a peak in the recovery time when the subjective discount rate is 0.08. If the world consumers have this subjective discount rate, they will face the longest transition possible to the new steady state.

In Appendix F (page 120) I present transitional dynamics for a similar model developed by Grossman and Helpman (1991a) where innovations are higher quality levels of products. The path to the new steady state is similar with the one presented in this section. The rate of innovation rises temporarily as a result of tighter IPRs and subsequently follows the saddle path to the new steady state.

2.4 Endogenous innovation (new varieties) and imitation

This model was developed by Grossman and Helpman (1991b) in order to determine the rate of innovation and imitation in the steady state equilibrium. My contribution to the model is to explain the transition dynamics of innovation and imitation when imposing stronger intellectual property rights. Innovation takes place in the North while the South imitates technologies that have been invented in the North. The North introduces new products at a constant rate $g = \dot{n}/n$, where n equals the number (measure) of products society knows how to produce. The South imitates Northern products at rate $m = \dot{n}_S/n_N$, where n_S represents the number of products that the South knows how to produce while n_N represents the number of products that the South has not yet imitated. The number of products society knows how to produce is $n_S + n_N = n$.

Consumers

This part is identical with the situation presented in Section 2.3 (page 46).

Research and Development (R&D)

The rate of innovation is defined as $g = \dfrac{\dot{n}}{n}$. The rate of imitation is defined as $m = \dfrac{\dot{n}_S}{n_N}$. If investment in Southern R&D (imitation) takes place, the reward from this activity, denoted by v_S, must cover R&D costs:

$$v_S = w_S(1+k)\frac{\mathrm{a}_S}{n_S} \tag{2.25}$$

where an increase in parameter k represents the imposition of stronger IPR The no-arbitrage conditions in asset markets imply for the South:

$$\frac{\pi_S}{v_S} + \frac{\dot{v}_S}{v_S} = \rho \tag{2.26}$$

where π_S represents instantaneous profits and ρ stands for the subjective discount rate.

For the North, the free entry condition (2.9) and the no-arbitrage condition (2.10) in asset markets are presented in Section 2.3 (page 48).

Producers

The pricing decisions for a Northern manufacturer (2.11) and the Northern profits (2.14) are presented in Section 2.3 (page 49).

A Southern manufacturer that imitated a Northern product can charge a monopoly price

$$p_S = \frac{w_S}{\alpha} \tag{2.27}$$

where w_S is the wage rate in the South (and equals the manufacturer's marginal cost).

A Southern firm charges a price $p_S = \frac{1}{\alpha} w_S$, makes sales x_S and has a marginal cost w_S. The instantaneous profits for these firms are:

$$\pi_S = \left(\frac{1}{\alpha}\, w_S - w_S\right) x_S = \left(\frac{1}{\alpha} - 1\right) w_S x_S = (1-\alpha) p_S x_S \tag{2.28}$$

The resource market (market clearing conditions)

We can express the labor market clearing conditions for the South by:

$$(1+k)\, \mathrm{a}_S \, \frac{\dot{n}_S}{n_S} + n_S\, x_S = L_S \tag{2.29}$$

where first term on the left-hand side represents employment in R&D while the second term represents employment in manufacturing. By definition $\dfrac{\dot{n}_S}{n_N} = m$. The market clearing condition for the North (2.16) is presented in Section 2.3 (page 49).

Equilibrium conditions:

The three differential equations that describe the equilibrium are (2.30), (2.31) and (2.32). In these equations g and m are jump variables while ζ is a state variable:

$$\dot{\zeta} = g - (m+g)\zeta \tag{2.30}$$

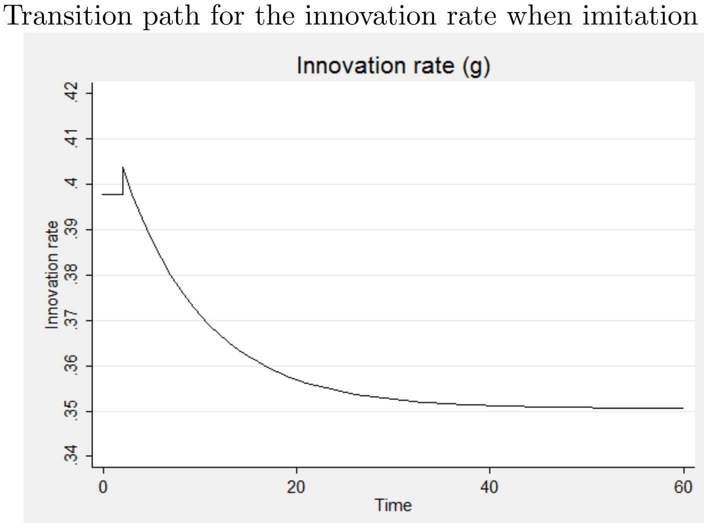
$$\dot{g} = \left(\frac{L_N}{\mathrm{a}_N} - g\right) \cdot \left[\rho + m + g - \frac{\left(\frac{1}{\alpha} - 1\right)\left(\frac{L_N}{\mathrm{a}_N} - g\right)}{\zeta}\right] \tag{2.31}$$

$$\dot{m} = \frac{1-\zeta}{\zeta}\left[\rho + \frac{m\zeta}{1-\zeta} - \frac{1-\alpha}{\alpha}\cdot\frac{L_S - \frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}}{(1+k)\mathrm{a}_S}\right]\cdot\frac{L_S - \frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}}{(1+k)\mathrm{a}_S} - \\ - \frac{m}{\zeta(1-\zeta)}\left[g - (m+g)\zeta\right] \quad (2.32)$$

Calculations deriving the above mentioned differential equations are presented in Appendix E.

The following numerical example will show the transitional dynamics following the imposition of stronger IPR. Set the unit labor requirement in innovation to $\mathrm{a}_N = 9$ and imitation $\mathrm{a}_S = 8.5$, and the discount rate to $r = .2$. Northern labor supply $L_N = 10$, Southern labor supply $L_S = 11$ and the initial IPR parameter $k = 0$ (which will increase to 0.1 when stronger IPR are imposed such that the labor requirement coefficient $(1+k)\mathrm{a}_S$ increases with stronger IPR). The rate of innovation rise temporarily as a result of tighter IPRs, but then it decreases below the initial steady-state. Imitation falls abruptly and then it continues to decrease to the new steady state. The fraction of goods that have not been imitated grows smoothly.

Figure 2.5: Transition path for the innovation rate when imitation is endogenous



The effects of imposing stronger intellectual property rights on the transition dynamics for the innovation and imitation rates depend on the parameters of the economy in question. The following tables shows how the transition paths are affected: for all cases in the following tables, the initial IPR parameter $k = 0$ will increase to 0.1 when stronger IPR are imposed such that the labor requirement coefficient $(1+k)\mathrm{a}_S$ increases with stronger IPR. Then I

Figure 2.6: Transition path for the imitation rate when imitation is endogenous

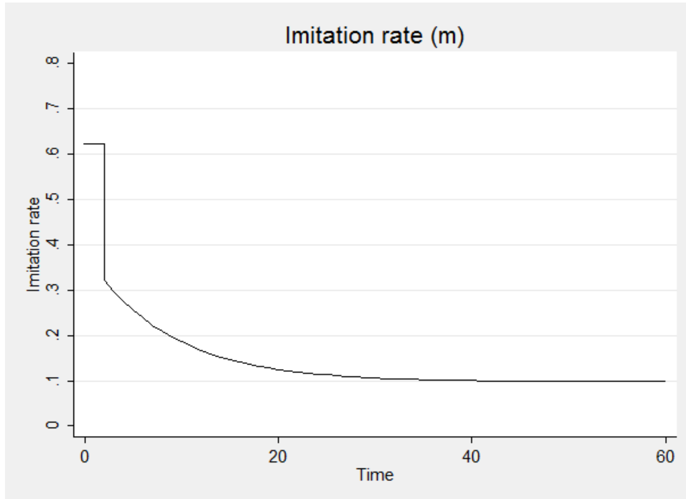
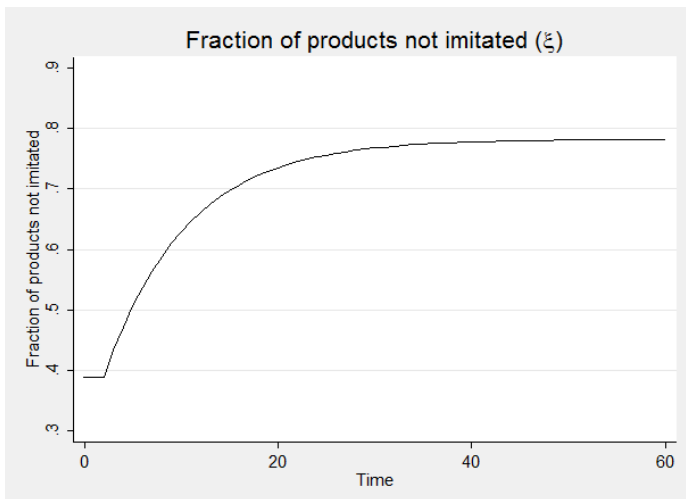


Figure 2.7: Transition path for the fraction of products not imitated when imitation is endogenous



analyze how changes in the Northern and Southern labor supply, the unit labor requirement in innovation and imitation, and other parameters affect the initial jumps (the jump amplitudes), the time it takes for the rate of innovation to return to the initial value on its way to the new steady state (return time) and the recovery time (the time required to go 99% of the distance between the initial steady state and the new steady state).

Table 2.5: Changes in the Northern labor supply L_N - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.45	0.7	1	1	0.6	0.2	0.01072	-0.38043	3.31804	65.1995
0.47	0.7	1	1	0.6	0.2	0.00899	-0.21439	3.35867	76.7137
0.5	0.7	1	1	0.6	0.2	0.00680	-0.11195	3.42568	99.9421
0.55	0.7	1	1	0.6	0.2	0.00386	-0.04933	3.55213	173.605
0.57	0.7	1	1	0.6	0.2	0.00286	-0.03708	3.6072	233.931

Table 2.6: Changes in the Southern labor supply L_S - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.5	0.62	1	1	0.6	0.2	0.00233	-0.02502	3.50026	245.969
0.5	0.67	1	1	0.6	0.2	0.00482	-0.06090	3.45349	132.158
0.5	0.7	1	1	0.6	0.2	0.00680	-0.11195	3.42568	99.9421
0.5	0.72	1	1	0.6	0.2	0.00839	-0.17969	3.40657	84.6135
0.5	0.75	1	1	0.6	0.2	0.01133	-0.44137	3.37568	67.0983

Table 2.7: Changes in unit labor requirement in innovation a_N - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.5	0.7	0.85	1	0.6	0.2	0.002010	-0.028802	3.659320	332.556000
0.5	0.7	0.87	1	0.6	0.2	0.002636	-0.034722	3.620500	253.832000
0.5	0.7	0.9	1	0.6	0.2	0.003578	-0.045507	3.567200	187.374000
0.5	0.7	0.95	1	0.6	0.2	0.005167	-0.070864	3.490100	130.446000
0.5	0.7	1	1	0.6	0.2	0.006800	-0.111953	3.425680	99.9421

Table 2.8: Changes in unit labor requirement in imitation a_S - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.5	0.7	1	0.98	0.6	0.2	0.00791324	-0.155804	3.412110	88.628300
0.5	0.7	1	0.99	0.6	0.2	0.007336	-0.131295	3.419010	94.0952
0.5	0.7	1	1	0.6	0.2	0.006800	-0.111953	3.425680	99.9421
0.5	0.7	1	1.01	0.6	0.2	0.006303	-0.096422	3.432160	106.214
0.5	0.7	1	1.015	0.6	0.2	0.006067	-0.089781	3.435330	109.526

Table 2.9: Changes in the subjective discount rate ρ - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.5	0.7	1	1	0.6	0.14	0.01294	-3.18386	4.99619	83.9553
0.5	0.7	1	1	0.6	0.15	0.01133	-0.96697	4.67188	87.625
0.5	0.7	1	1	0.6	0.17	0.00901	-0.29606	4.10438	93.5233
0.5	0.7	1	1	0.6	0.2	0.00680	-0.11195	3.42568	99.9421
0.5	0.7	1	1	0.6	0.21	0.00626	-0.08895	3.23681	101.633

Table 2.10: Changes in the measure of substitutability α - Endogenous imitation

L_N	L_S	a_N	a_S	α	ρ	Jump in g	amplitudes in m	Return time	Recovery time
0.5	0.7	1	1	0.55	0.2	0.00933	-0.46513	3.46589	84.9132
0.5	0.7	1	1	0.58	0.2	0.00772	-0.18374	3.43975	93.5702
0.5	0.7	1	1	0.6	0.2	0.00680	-0.11195	3.42568	99.9421
0.5	0.7	1	1	0.62	0.2	0.00597	-0.07245	3.41605	106.903
0.5	0.7	1	1	0.66	0.2	0.00456	-0.03410	3.40555	123.067

These calculations confirm a few important relationships. When the size of the Northern labor force is larger, the time necessary to reach the new steady state increases. This result is different from the case with exogenous imitation. The opposite is true when the Southern labor force increases and the transition to the new steady state is longer. Looking at the unit labor requirement in innovation we can say that an increase in this value will decrease the recovery time (yielding a different result from the case with exogenous imitation). Increasing the labor requirement in imitation will prolong the transition. Changes in the subjective discount rate generate the biggest variations in the return and recovery times.

In Appendix G (page 139) I present transitional dynamics for a similar model developed by Grossman and Helpman (1991a) where innovations are higher quality levels of products. The path to the new steady state is relatively similar with the one presented in this section, with the exception of the imitation rate. The rate of innovation rises temporarily as a result of tighter IPRs and subsequently follows the saddle path to the new steady state, like before. Imitation however falls abruptly and than it starts increasing slowly reaching a new steady state below the initial one. The amount of products produced in the North grows smoothly.

2.5 Conclusions

An example to support the importance of transitional dynamics analysis is the imposition of product patent protection for pharmaceutical products in India following the 1995 TRIPs agreement. In 2005 India implemented product patent protection, preventing Indian firms from selling reverse-engineered products (developed after 2005). What changes should we expect in the Indian pharmaceutical market? In my first essay ("IPRs, Innovation, Imitation and Offshoring: The Case of the Indian Pharmaceutical Industry"), using a panel of 354 Indian pharmaceutical firms over the period 1989 to 2008, I present the adjustments of the rates of innovation, imitation following the change in the intellectual property rights policy in India. Based on the work of Grossman and Helpman (1991a and 1991b) and the other authors who employed their models, one would expect a swift shift in the rates of innovation and imitation to the new steady state after the policy change. The empirical results presented in my first essay suggest gradual transitions to the new steady states as the economy doesn't adjust immediately to the new steady state.

At the beginning of this chapter I presented the work of Helpman (1993) in analyzing the short-run and long-run effects of stronger IPRs on innovation in a simpler model with exogenous imitation. He finds that a reduction in the rate of imitation results in a long run decline in the rate of innovation and an increase in the fraction of products that have not been imitated. In the short run though, innovation rises temporarily. Using the framework employed by Helpman (1993) I analyze in Section 2.3 how the transition between steady states (in terms of initial jump size and transition time to the new steady state) depends on parameters of the model. I employ numerical simulations to see how changes in the Northern labor supply, the unit labor requirement, the subjective discount rate, and the elasticity of demand affect the transition path. In Appendix F, I analyzed the transition dynamics of imposing stronger intellectual rights in a similar model with endogenous innovation (quality improvement) and exogenous imitation based on the Grossman and Helpman (1991b) model. I have shown that the steady state equilibrium of this model is saddle point stable. The path to the new steady state is similar with the one when innovations are new varieties. The rate of innovation rises temporarily as a result of tighter IPRs and subsequently follows the saddle path to the new steady state.

Based on the analysis presented in Section 2.4 (when innovations are new varieties) and Appendix G (when innovations are higher quality levels), a decrease in imitation due to stronger Southern IPR protection (an increase in the labor requirement for imitation, k) always shifts production from the South to the North and hence takes Northern labor away from innovation. Both innovation and imitation fall in the long run (steady state) regardless of the innovation type. In the short run, stronger Southern IPR protection promotes innovation and discourages imitation for both types of models. In the case of new varieties development, imitation decreases in the short run followed by a further decrease towards the new steady state. In the case of quality improvements, imitation decreases in the short run and then increases while adjusting to the new steady state. At the end of Section 2.4 I show how the transition between steady states depends on parameters of the model. I employ numerical simulations to see how changes in the Northern and Southern labor supply, the unit labor requirement in innovation and imitation, the subjective discount rate, and the elasticity of demand affect the transition path. When the size of the Northern labor force is large, the time necessary to reach the new steady state is longer. This result is different from the case with exogenous imitation. The opposite is true when the Southern labor force is large and the transition to the new steady state increases. Looking at the unit labor requirement in innovation we can say that an increase in this value will decrease the recovery time (yielding a different result from the case with exogenous imitation). Increasing the labor requirement in imitation will prolong the transition. Changes in the subjective discount rate generate the biggest variations in the return and recovery times.

In this essay I discussed how changes in the size of the North to the South affect the transition dynamics of innovation and imitation. In real life both countries experience increases in their labor force. My next estimations will include an equi- proportional increase in both countries' labor supply. Would they cancel each other?

Chapter 3

Intellectual Property Rights Regimes and the Choice of Offshoring in the Pharmaceutical Market

3.1 Introduction

The "make-or-buy" decision is fundamental to industrial organization. Making a new finished product requires a firm not only to research and design the good, but it also necessitates the production or sourcing of its components. For each one of these activities a producer must decide whether to undertake the activity in-house or to purchase the input or service from another firm that may be located abroad. This decision of whether to produce in-house or purchase the good (either the final good or intermediate goods) from lower-cost countries or countries with better legal institutions can best be understood through the expansion of trade models to include concepts from industrial organization and contract theory that explain the vertical organization of production. The combination of trade literature with the industrial organization literature (regarding the choice of organizational form) represents an important new area for both theoretical and empirical research. A firm can purchase an input/activity from a vertically integrated supplier located abroad or can purchase it from an independent firm located abroad, so-called arm's length contracting. In this chapter I analyze the choice of a domestic firm between performing R&D at home, forming a joint venture abroad with an existing foreign firm and purchasing R&D from abroad. The trade-offs between these three organizational choices are modeled in Section 3.3.

The theoretical papers analyzing the choice between vertical integration and arm's length contracting can be grouped into two categories based how the tradeoff between the two organizational choices is modeled. An incentive-system approach employed by Grossman and Helpman (2002, 2004) involves optimal incentive contracts designed by a principal to induce investment or effort by managers. The property rights approach is employed by Antras (2003) and Antras and Helpman (2004). This approach emphasizes that ownership and control should be allocated so as to minimize the loss in surplus due to investment distortions. My work belongs to this second strand. The previous author's work and the connection to my chapter is presented in the next section of the chapter.

Several papers have observed that offshoring is evolving from manufacturing inputs to business services and research and development.[1] The R&D offshoring decision of firms represents an important new area of research. The process of creating knowledge can be the result of a single firm effort or the result of cooperation between firms. As technology becomes more advanced it becomes more difficult for individual firms to develop new technologies based on their own abilities, and the importance of cooperation increases. In the last years, there has been a significant increase in the number as well as in the forms of cooperative R&D projects.[2] Most of the papers on cooperative R&D analyze its main advantages and its potential disadvantages. Among the advantages are the internalization of spillovers, the capture of economies of scale, the diffusion of know-how and R&D output between the partners, or avoidance of the duplication of efforts. One potential disadvantage pointed out by some authors is that firms could use cooperation to reduce the competition in the product market, resulting in a welfare loss. Among the authors who contributed to this literature we can mention Katz (1986), d'Aspremont and Jacquemin (1988), and Kamien et al.(1992).

This cooperation is not limited to firms within a country. Firms from different countries

[1] Campa and Goldberg [1997], and Hummels, Rapoport, and Yi [1998] are a few examples.

[2] Hagedoorn et al. (2005).

now join forces in order to develop new products or new technologies of production. Effective protection of intellectual property rights, through patent laws and their enforcement, reduces the risk for companies when they engage in various international R&D activities. In general, any international transaction with a company from a country with a well-established intellectual property rights regime is less likely to be subject to substantial misuse of information (R&D) than transactions with companies from countries that offer little or no protection. With R&D cooperation, there is always the risk of unanticipated knowledge leakage and IPR protection can be expected to be even more important in these than in other international transactions and investments. Pharmaceutical firms are confronted with higher knowledge leakage hazards and potentially higher subsequent costs when they engage in contractual agreements with companies from countries with relatively weaker IPR institutions.[3] Pisano (1989), Hagedoorn (2002) and Hagedoorn et al. (2005) argue that the choice of intellectual property rights protection not only affects the decision of firms to perform cooperative R&D abroad, but also affects the type of partnership (contracting out R&D or creating joint ventures abroad). Based on their empirical studies they conclude that joint ventures are expected to be reserved for circumstances with greater knowledge leakage hazards because they offer managerial and organizational control and increase the possibilities for adequate monitoring and oversight. Their work is presented in the next section of the paper.

This chapter brings three important contributions to the literature. First, it provides theoretical support to the idea that the level of intellectual property rights protection, the wage gap between the two countries and the fixed cost of establishing a joint venture influence the type of offshoring. Second, it investigates the role of R&D offshoring over the choice of organizational structure in international collaboration. When a firm decides to offshore part of its R&D activity to a different country, the IPR protection in the destination country is an important concern and firms might choose to form joint ventures in order to have more control over the collaboration and prevent leakage of information. But the property-rights aspect of the R&D activity is not the only element that might influence the organizational

[3] Oxley, Joanne E. (1999).

choice of an offshoring firm. It has been suggested in the literature[4] that firms choose to form joint ventures in order to take advantage of transfer-pricing opportunities in countries with less taxation. This is especially true in the case of R&D activity when government authorities would have a hard time to find a similar arm's length contract to compare with the joint venture contract and decide whether or not the price paid for a certain R&D service was overinflated. In this paper I look at the overall effect of R&D offshoring over the choice of organizational structure. Third, I analyze data from the pharmaceutical market and find three regularities that support my theoretical model. The first finding is that the strength of IPRs protection in the home country has a significant influence over the decision to form a joint venture or to sign a contractual partnership. Also, the preference of a company for extra control (forming a joint venture) is inversely related with the wage gap between the two countries. Lastly, I find that the fixed cost of establishing a joint venture acts as a deterrent to forming a joint venture while the nature of the R&D process promotes the formation of joint ventures.

In the model presented below I study the joint effect of different regimes of intellectual property rights protection, the wage gap and the fixed cost of starting a business on the preference of companies for particular forms of international R&D partnership. In particular, I look at the choice for either international joint ventures or contractual international sourcing, also known as contract research and manufacturing services(CRAMS). In this context, I pay attention to a number of specific issues that refer to the international differences in intellectual property rights protection and the different forms of international partnership.

According to the model, lower wages in the South and higher wages in the North are important incentives for offshoring but these are not the only factors that influence a company's offshoring decision. For a given wage gap between the two countries, weaker IPR (a higher probability of imitation) in the destination country and a higher fixed cost required by the participation (in the case of joint venture) will provide a lower incentive for international collaboration. When choosing between the two offshoring strategies, a Northern firm will face a tradeoff between the benefits of lower imitation risks associated with creating a joint venture

[4] Antras, Pol and Helpman, Elhanan (2004).

and the local costs of establishing the joint venture.

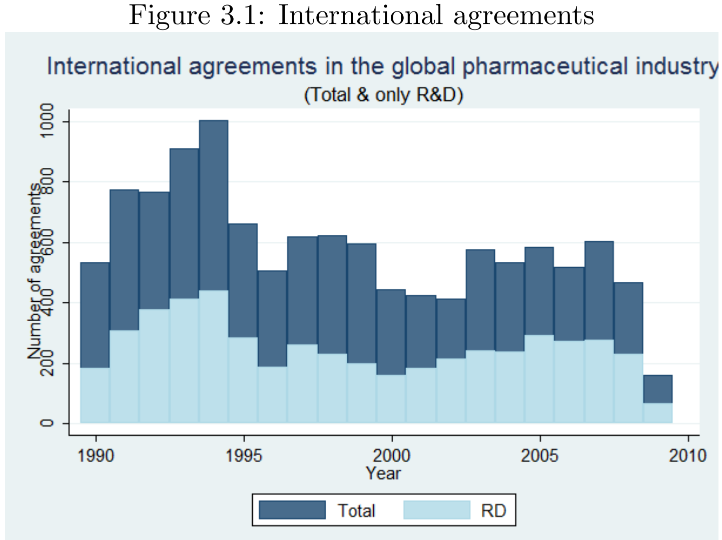
I test these predictions using country-level data and a binomial logit estimation technique. I use partnership data regarding the pharmaceutical industry for a panel of 89 countries over the period 1990 to 2009. These data are part of the SDC Platinum dataset. I combine this information with the Ginarte-Park index as a measure for IPR protection, wage data from the Yearbook of Labour Statistics (at 3 digit industry level, where available) and the number of days it takes to start a business from the World Bank Group.

The pharmaceutical industry provides an interesting example given the importance that IPR protection has in this sector and the changes that took place in the last twenty years in terms of IPR protection across the world. In 1995, signatories to the TRIPs agreement agreed as a condition of membership in WTO to grant product patents by 2005 for pharmaceutical innovations. Since 2005, firms from signatory countries have not been able to sell reverse-engineered (copied) products under patent protection. Their activity is limited to developing new products, producing under licence and manufacturing off-patent products or bulk products. Firms in developing countries expand their reach towards other markets by purchasing plants abroad or by forming joint-venture with local foreign firms. [5] For example, Ranbaxy of India has purchased production facilities in seven foreign countries (China, Ireland, Malaysia, Nigeria, Romania, U.S.A. and Vietnam). In South Africa, it formed a subsidiary with a local firm (Adcock Ingram) to promote sales of their products on the local market. This is a very common strategy for Indian firms to speed up market approvals and improve customer acceptance of their products. Cipla of India formed joint ventures with Eli Lilly (to sell products in U.S.), Novopharm (to sell products in Canada) and Enaleni Pharmaceuticals Limited (to sell products in South Africa). Lupin of India collaborates with Merck Generics (to sell products in U.K.) and McGaw Inc. (to sell products in U.S.). Collaboration between local firms and multinational companies is not limited to production or marketing. Recent collaboration was targeted towards research and development of new products. For example, Ranbaxy has a global alliance with GlaxoSmithKline Plc. regarding research and development activities and

[5] These facts are drawn from Smith (2002)

with Eli Lilly regarding clinical trials of drugs. Although the 1995 changes in IPR protection across the world should have increased the international cooperation between firms, data presented in the SDC Platinum database depicts a different situation. After 1995 the number of international agreements sharply decreased reflecting the idea that some firms postponed their cooperation plans until the new legislation is implemented in 2005. In 2005 the number of international agreements increases but it doesn't reach the previous level because of the global economic crisis that followed. The figure below shows a relative constant fraction of R&D contracts in the total number of international agreements suggesting that the change was not skewed towards R&D contracts.

Figure 3.1: International agreements



The literature review is presented in Section 3.2 and Section 3.3 describes the model. Section 3.4 presents data and a discussion the estimation results. Concluding remarks are made in Section 3.5. In the Appendix H I present a special case of demand which allows me to to pinpoint the analytical relationship between the choice of organizational structure and the IPR protection, the wage gap between countries and the cost of starting a business. Tables describing the variables and the estimation results are shown in Appendix I.

3.2 Literature review

In the recent years there is a growing role for multinational corporations in the global economy and these multinational firms explore more complex integration strategies. These developments generated an increased interest in new theoretical approaches designed to better understand how firms organize production on a global scale. In developing these complex offshoring strategies firms decide where to locate the production of different parts of their value chains and also on the extent of their control over these activities. Which activities should they locate in the home country and which should they offshore? If they choose to offshore, should they engage in an equity-based international partnership and import intermediate inputs within their firm boundaries or should they offshore the production to independent foreign suppliers? This paper studies the effect of different regimes of intellectual property rights protection on the preference of companies for particular forms of international R&D collaborations. It particularly looks at the choice for either equity-based international R&D joint ventures or contractual international R&D activities. In this context, I should focus my attention to a number of specific issues that refer to the international differences in intellectual property rights protection and the differences between these two forms of international R&D activities.

As mentioned before the literature analyzing the choice between vertical integration and arm's length contracting can be grouped in two categories based on how the tradeoff between the two organizational choices is modeled. The first group models the tradeoff within the context of a principal-agent model while the second group models the tradeoff as a function of property rights. As part of the first group, Grossman and Helpman (2002) address the choice between outsourcing and integration in a one-input general equilibrium framework, assuming that all firms of a given type are equally productive. Firms face the friction of incomplete contracts in arm's-length relationships, which they weigh against the less efficient production of inputs in integrated companies. As a result, some sectors have only vertically integrated firms whereas others have only "arm's-lenght" agreements. Grossman and Helpman (2004) extend upon their previous paper by connecting it with previous research on the organization of the firm and optimal design of contracts for managers. In this paper principals are unable to monitor all of the actions undertaken by their agents and the ability to monitor varies with proximity. The principal faces the choice of whether to engage the agent as manager or supplier in its home country or to seek to import the intermediate inputs from a subsidiary or supplier located in a foreign land. The manager receives a non-negative wage provided that he performs satisfactorily on tasks that the principal can monitor and a bonus that he receives if the project succeeds. In an outsourcing relationship (either domestic or international), the agent receives a payment from the principal that will be paid no matter how the project turns out and an amount that will be paid in return for delivery of acceptable components. They conclude that a principal may benefit from engaging an external supplier to manufacture components because this agent has more at stake (he bears the cost of the inputs needed to manufacture components) and the cost to the principal to induce very high level of effort is less than for an employee. The advantage of in-house production stems from the greater opportunity for the principal to monitor the actions of the agent. In my chapter I consider the idea that weak intellectual property rights protection in a country is the source of possible information leakage and loss of profits rather than an agent performing poorly due to the inability of the principal to monitor its actions due to proximity issues like in Grossman and Helpman (2002, 2004). In my essay a firm benefits from having an arm's-length supplier by avoiding the fixed costs of creating a joint venture but faces a higher risk of information leakage if there is weak protection of IPRs in the destination country. The advantage of forming a joint venture with a foreign firm stems from the greater opportunity for the firm to monitor the actions of the joint venture.

As part of the second group of organizational choice literature, Antras (2003) focuses on the tradeoff between vertical integration and offshoring when relationship-specific investments are distorted because enforceable agreements take place only ex-post or after investment is sunk. The surplus or economic rent created by the relationship is distributed through ex-post Nash bargaining. The ownership of assets is fundamental for each party's incentive to invest, since it determines the residual rights of control and hence the outside option or threat point of each party. Antras (2003) develops a property-rights model of the boundaries of the firm and embeds it into a general equilibrium monopolistic competition model of trade in which countries differ in their endowments of labor and capital. The model explains trade based on differences in endowments of factors across countries and monopolistic competition arising from consumer demand for variety. He provides evidence that capital-intensive intermediate goods, such as chemical products, tend to be imported into the US within the boundaries of multinational firms, while labor intensive goods, such as textiles, are imported from unaffiliated parties. Also, the capital-labor ratio in the exporting country is a positive function of the share of intrafirm imports by multinationals as a proportion of total U.S. imports. Thus U.S. imports from capital abundant countries, such as Switzerland, tend to involve multinationals, whereas imports from capital scarce countries, such as Egypt, occur mostly at arms length. To explain these results, Antras (2003) assumes a continuum of varieties of final goods in each of two sectors, which differ by capital intensity due to a requirement for a specialized intermediate input produced with both capital and labor. The opening of trade leads to an integrated world economy in which factor prices are equalized, but since final goods are assumed to be non-tradeable, the entire volume of world trade is in intermediate inputs.

In order to address the question of why multinational firms engage in different integration strategies Antras and Helpman (2004) developed a two-country model of international trade. Firms in the North develop differentiated products and they decide whether to integrate the production of intermediates or outsource them. In either case firms have to decide in which country to source these inputs, in the high-cost North or the low-cost South. In choosing between a domestic and a foreign supplier of parts, a final good producer faces a tradeoff between the benefits of lower variable costs in the South and the benefits of lower fixed costs in the North. On the other hand, in choosing between vertical integration and outsourcing (either domestic or international), the final good producer has to decide between the benefits of ownership advantage from vertical integration and the benefits of better incentives for the independent supplier of parts. These tradeoffs induce firms with different productivity levels to sort by organizational form. They find that high productivity firms acquire intermediate inputs in the South whereas low productivity firms acquire them in the North. Among firms that source their inputs in the same country, the low productivity firms outsource whereas the high productivity firms insource. The cost structure of my chapter is similar to the model presented by Antras and Helpman (2004): Northern firms face lower variable costs in the South. However, they only face fixed costs if they decide to form a joint venture rather than contracting out their activities. When choosing between forming a joint venture and contracting out, the Northern firms weighs the benefits of better monitoring advantage due to ownership in the joint ventures agasint the benefits of no fixed costs for the arm's-length contracts. These tradeoffs induce firms to offshore their activities if the wage gap between North and South is large enough. Firms that offshore their activities choose to organize as joint ventures if there is weak protection of IPRs in the destination country or to contract activities at arm's-length if the costs of forming joint venture are high or there is strong protection of IPRs in the destination country.

On the empirical side this paper builds on a number of previous studies, such as Ginarte and Park (1997), Briggs (2007), Pisano (1989), Oxley (1999) and Hagedoorn et al. (2005). Ginarte and Park (1997) construct an index of patent rights for 110 countries for the period 1960–1990. The index is used to examine what factors or characteristics of economies determine how strongly patent rights will be protected. The evidence does indicate that more developed economies tend to provide stronger protection. But the underlying factors which influence patent protection levels are the country's level of research and development (R&D) activity, market environment, and international integration, which are correlated with its level of development. Building on the index developed by Ginarte and Park (1997), Briggs (2007) investigates the validity of a previous conclusion in the IPRs literature that the optimal choice of IPRs will first decrease as a country develops before it increases. She concludes that the known U-shape is a result of cross-country differences originating in the year that each country first chooses to implement IPRs, rather than a result of a longitudinal trend. Countries usually maintain or increase IPRs over time as they progress through stages of development. In my paper I employ the Ginarte and Park index to account for differences across countries that might influence the offshoring decision of pharmaceutical firms.

Pisano's (1989) study considered intellectual property rights protection and the preference for particular forms of inter-firm partnership in the US biotechnology industry. His study suggests that companies prefer equity-based partnerships to contractual agreements when they are confronted with higher levels of specific knowledge transfer, when uncertainty surrounding partnerships increases. Oxley's (1999) study on a set of questions similar to the ones I have presented gives an analysis of the choice between equity and contractual partnerships from the perspective of US companies within a limited number of high-tech sectors. Her study indicates that in international partnerships established during the 1980s both the nature of the actual transactions within a partnership and the 'quality' of the institutional environment for intellectual property rights protection affect the preference for equity or contractual partnerships. When US companies were partnering companies from countries with weaker intellectual property rights protection standards, they preferred to enter into an equity-based partnership rather than engage in a contractual agreement.

Following the direction of Oxley (1999), I analyze intellectual property rights protection and the preference of companies for particular forms of international partnerships for the pharmaceutical industry for companies from a large number of countries. This study contains over 11,000 international partnerships from 89 countries. My research focuses on the period from the 1990 to the end of 2009 when intellectual property rights protection, and in particular patent-related property rights protection, appeared to diverge substantially between many countries at different levels of economic and technological development. My contribution highlights a number of important aspects of the international strategic behavior of companies and their choices with regard to the form of international partnering in the context of intellectual property rights protection.

Hagedoorn et al.(2005) extended the work of Oxley (1999). They categorize the R&D cooperation activities as two forms of partnership: joint ventures and contractual R&D partnerships. Joint ventures are separate organizational units created and controlled by a parent company. Joint ventures represent a relatively high level of hierarchical control, as parent companies share formal control over the joint venture through equity sharing. In general, the ownership structure of joint ventures is determined by equity participation through the ex-ante allocation of ownership shares to the parent companies. This generates a governance structure where the sponsoring companies can monitor the activities of the joint venture as they are represented on the board of directors. Contractual R&D activities, such as joint R&D pacts and R&D purchases, cover R&D activities of one or more companies on a project basis. Such undertakings imply the temporary sharing of some R&D resources in R&D projects or R&D programs for which companies agree on the shared input of human resources, technologies, laboratories and equipment. Compared with R&D joint ventures, contractual R&D partnerships are characterized by a lower level of hierarchical control.

Hagedoorn et al.(2005) analyze a sample of 2,005 international R&D partnerships, taken from the MERIT-CATI databank[6] These 2,005 partnerships are sponsored by 1956 companies from 53 countries. Of these international R&D partnerships, 35% are joint ventures and 65% are contractual R&D partnerships. They test the hypotheses that differences in the regime of intellectual property rights protection in the home countries of partnering companies and the sectoral level of technological change influence the preference for an equity R&D joint venture or a contractual R&D partnership. The estimation method is a binomial logit analysis. They find that international differences in intellectual property rights protection are a significant factor in the choice of R&D cooperation: with less secure protection, firms choose R&D joint ventures rather than contractual partnerships. The level of technological change in industries has an inverse effect on the preference for international R&D joint ventures.

Following Hagedoorn et al. (2005) I employ a theoretical model to study the joint effect of different regimes of intellectual property rights protection, the wage gap and the fixed cost of starting a business on the preference of companies for particular forms of international R&D partnership. In particular, I look at the choice for either international joint ventures or contractual international sourcing. In this context, I pay attention to a number of specific issues that refer to the international differences in intellectual property rights protection and the different forms of international partnership. In order to test the conclusions of the theoretical model, in this section I look at the determinants of international partnership in 89 countries over the period 1990 to 2009.

[6]The MERIT-CATI database is a literature-based database that draws on sources such as newspapers, journal articles, books, and specialized journals that report on business events. The MERIT-CATI databank contains information on thousands of technology-related inter-firm partnerships in various sectors, ranging from high-technology sectors such as pharmaceutical biotechnology to less technology-intensive sectors such as food and beverages. This database includes business alliances with an R&D or technology component such as joint research or development agreements, R&D contracts, and equity joint ventures.

3.3 The Model

Pharmaceutical firms, in an attempt to reduce operating costs, are turning towards different R&D offshoring strategies that take advantage of less expensive skilled labor in countries like India. Intellectual property protection plays an important role in determining the conditions under which a certain type of R&D offshoring will take place. We consider two models of R&D offshoring: joint ventures and purchased R&D (CRAMS - contract research and manufacturing services). In this section we assume that firms choose the price that will maximize their profits for each one of the three alternatives: perform R&D at home, buy R&D from a Southern firm, or form a joint venture with a Southern firm.

Northern firms can perform R&D in the North or they can offshore the activity in the South in order to take advantage of lower labor costs. If offshoring is attractive, then the Northern firm has to choose between a joint venture and purchased R&D. If the Northern firm will keep R&D at home, there will be no risks but the costs (wages) will be higher. When creating a joint venture, the Northern firm will have to pay a fixed cost and will face the probability μ that imitation will occur and that the research results will be available to at least one competitor (given that firms compete in prices, this will drive the rent associated with this research to zero). If the Northern firm decides to purchase R&D from a Southern firm, it will face the risk of being imitated (γ) and will not have to pay the fixed costs. In this case, the risk of imitation can be thought as the Southern firm selling the R&D to a competitor. The profits associated with these activities will depend on prices charged, quantity sold (products based on that technology), risks and costs.

The two imitation probabilities are decreasing functions of IPR strength. Considering a simple linear functional form we assume that:

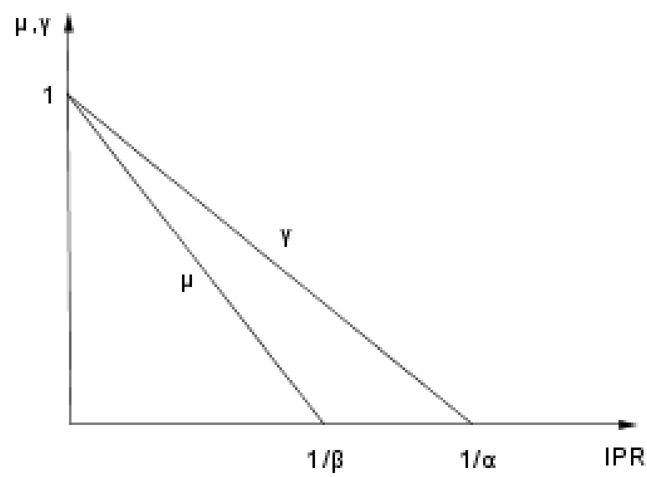
$$\gamma = 1 - \rho \,\mathrm{IPR} \tag{3.1}$$

$$\mu = 1 - \eta \,\mathrm{IPR}, \quad \text{where IPR} \geq 0, \text{ and } \rho, \eta \in [0, 1] \tag{3.2}$$

When the two offshoring strategies face the same risk of imitation, the Northern firm will prefer to buy the R&D from the South (if it gives higher profits than doing research at home) because it avoids paying the fixed costs associated with joint venture. If the inequality holds as equality, then the Northern Firm is indifferent between creating a joint venture and buying R&D from the South. In order for joint venture to exist, the risk of imitation when buying the R&D (γ) has to be bigger than the risk of imitation when creating a joint venture (μ).

To overcome the advantage that buying R&D has over forming a joint venture (the fixed costs), we can assume that firms will be better able to better avoid imitation for a weak level of IPR in the case of joint ventures as opposed to buying R&D from the South. Considering the functional form for the two types of imitation ($\gamma = 1 - \rho\,\mathrm{IPR}$, and $\mu = 1 - \eta\,\mathrm{IPR}$), the above assumption can be seen as μ having a steeper slope than γ (meaning that $\eta > \rho$, where $\rho, \eta \in [0, 1]$). This relationship corresponds to the idea that in a joint venture the Northern firm has a better control over the R&D process for any given level of intellectual property rights. [7] As the protection of intellectual property rights strengthens, the risk of imitation decreases for both types of offshoring but the change is faster in the case of a joint venture. This relationship is depicted in figure 3.2 below.

Figure 3.2: IPRs and the risk of imitation



[7]Hagedoorn et al. (2005).

A firm that successfully performed R&D resulting in an innovation chooses the price that will maximize its profits. A Northern firm that successfully performed R&D at home, will earn the following profits:

$$\pi_H = (p_N - \mathrm{w}_N)x_N \tag{3.3}$$

Consider that there is uncertainty about the demand for the firm's product such that the demand is given by $x_N = \alpha - \beta p_N + \varepsilon$. This linear demand has an independent and identically distributed error term ε that takes on a normal distribution: $\varepsilon \sim N(0, \sigma)$

Substituting in the demand, we can rewrite the profits as

$$\pi_H = (p_N - \mathrm{w}_N)(\alpha - \beta p_N + \varepsilon) \tag{3.4}$$

Firms maximize their expected profits by choosing the optimal price. The first order conditions for the home production choice are:

$$\frac{\partial E(\pi_H)}{\partial p_N} = \alpha - \beta \cdot 2p_N + \mathrm{w}_N\beta = 0 \tag{3.5}$$

$$2\beta p_N = \alpha + \mathrm{w}_N\beta \implies p_N = \frac{\alpha + \mathrm{w}_N\beta}{2\beta} \tag{3.6}$$

Therefore, by substituting the optimal price back into the profit function we find that

$$\begin{aligned}
\pi_H &= \left(\frac{\alpha + \mathrm{w}_N\beta}{2\beta} - \mathrm{w}_N\right)\left(\alpha - \beta\frac{\alpha + \mathrm{w}_N\beta}{2\beta} + \varepsilon\right) \\
&= \left(\frac{\alpha}{2\beta} + \frac{\mathrm{w}_N}{2} - \mathrm{w}_N\right)\left(\alpha - \frac{\alpha}{2} - \frac{\mathrm{w}_N\beta}{2} + \varepsilon\right) = \\
&= \left(\frac{\alpha}{2\beta} - \frac{\mathrm{w}_N}{2}\right)\left(\frac{\alpha}{2} - \frac{\mathrm{w}_N\beta}{2} + \varepsilon\right) = \\
&= \frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_N}{4} - \frac{\alpha\mathrm{w}_N}{4} + \frac{{\mathrm{w}_N}^2\beta}{4} + \frac{\alpha\varepsilon}{2\beta} - \frac{\mathrm{w}_N\varepsilon}{2} = \\
&= \frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_N}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_N}^2\beta}{4} - \frac{\mathrm{w}_N\varepsilon}{2}
\end{aligned} \tag{3.7}$$

Similar calculations can be done for the joint venture alternative. The profit function in this case is

$$\pi_{JV} = (1-\mu)(p_N - \mathrm{w}_S)x_N - F \tag{3.8}$$

As before, there is uncertainty about the firm‘s demand $x_N = \alpha - \beta p_N + \varepsilon$. Taking into account the demand function we can rewrite the profits of a joint venture as

$$\pi_{JV} = (1-\mu)(p_N - \mathrm{w}_S)(\alpha - \beta p_N + \varepsilon) - F \tag{3.9}$$

Firms maximize their expected profits by choosing the optimal price. The first order conditions for the joint venture production choice are:

$$\frac{\partial E(\pi_{JV})}{\partial p_N} = (1-\mu)\left(\alpha - \beta \cdot 2p_N + \mathrm{w}_S\beta\right) = 0 \tag{3.10}$$

$$2\beta p_N = \alpha + \mathrm{w}_S\beta \implies p_N = \frac{\alpha + \mathrm{w}_S\beta}{2\beta} \tag{3.11}$$

Therefore, by substituting back into the profit function the optimal price we find that

$$\begin{aligned}
\pi_{JV} &= (1-\mu)\left(\frac{\alpha + \mathrm{w}_S\beta}{2\beta} - \mathrm{w}_S\right)\left(\alpha - \beta\frac{\alpha + \mathrm{w}_S\beta}{2\beta} + \varepsilon\right) - F \\
&= (1-\mu)\left(\frac{\alpha}{2\beta} + \frac{\mathrm{w}_S}{2} - \mathrm{w}_S\right)\left(\alpha - \frac{\alpha}{2} - \frac{\mathrm{w}_S\beta}{2} + \varepsilon\right) - F = \\
&= (1-\mu)\left(\frac{\alpha}{2\beta} - \frac{\mathrm{w}_S}{2}\right)\left(\frac{\alpha}{2} - \frac{\mathrm{w}_S\beta}{2} + \varepsilon\right) - F = \\
&= (1-\mu)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_S}{4} + \frac{\alpha\varepsilon}{2\beta} - \frac{\alpha\mathrm{w}_S}{4} + \frac{{\mathrm{w}_S}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) - F = \\
&= (1-\mu)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_S}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) - F
\end{aligned} \tag{3.12}$$

The last alternative is buying R&D from the South. The profit function in this case is

$$\pi_{BUY} = (1-\gamma)(p_N - \mathrm{w}_S)x_N \tag{3.13}$$

As before, there is uncertainty about the firm‘s demand $x_N = \alpha - \beta p_N + \varepsilon$. Taking into account the demand function we can rewrite the profits of a firm buying R&D as

$$\pi_{BUY} = (1-\gamma)(p_N - \mathrm{w}_S)(\alpha - \beta p_N + \varepsilon) \tag{3.14}$$

Firms maximize their expected profits by choosing the optimal price. The first order conditions are:

$$\frac{\partial E(\pi_{BUY})}{\partial p_N} = (1-\gamma)\left(\alpha - \beta \cdot 2p_N + \mathrm{w}_S\beta\right) = 0 \tag{3.15}$$

$$2\beta p_N = \alpha + \mathrm{w}_S\beta \implies p_N = \frac{\alpha + \mathrm{w}_S\beta}{2\beta} \tag{3.16}$$

Therefore, by substituting back into the profit function the optimal price we find that

$$\begin{aligned}
\pi_{BUY} &= (1-\gamma)\left(\frac{\alpha + \mathrm{w}_S\beta}{2\beta} - \mathrm{w}_S\right)\left(\alpha - \beta\frac{\alpha + \mathrm{w}_S\beta}{2\beta} + \varepsilon\right) \\
&= (1-\gamma)\left(\frac{\alpha}{2\beta} + \frac{\mathrm{w}_S}{2} - \mathrm{w}_S\right)\left(\alpha - \frac{\alpha}{2} - \frac{\mathrm{w}_S\beta}{2} + \varepsilon\right) = \\
&= (1-\gamma)\left(\frac{\alpha}{2\beta} - \frac{\mathrm{w}_S}{2}\right)\left(\frac{\alpha}{2} - \frac{\mathrm{w}_S\beta}{2} + \varepsilon\right) = \\
&= (1-\gamma)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_S}{4} + \frac{\alpha\varepsilon}{2\beta} - \frac{\alpha\mathrm{w}_S}{4} + \frac{\mathrm{w}_S{}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) = \\
&= (1-\gamma)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_S{}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right)
\end{aligned} \tag{3.17}$$

A Northern Firm will choose to create a joint venture over performing R&D at home if:

$$\begin{aligned}
\pi_{JV} &> \pi_H \\
(1-\mu)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_S{}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) - F &> \\
> \frac{\alpha^2}{4\beta} - \frac{\alpha\mathrm{w}_N}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_N{}^2\beta}{4} - \frac{\mathrm{w}_N\varepsilon}{2} \\
-\frac{\mu\alpha}{2\beta}\left(\frac{\alpha}{2} + \varepsilon\right) + \left(\frac{\alpha+\varepsilon}{2}\right)\left((\mathrm{w}_N - \mathrm{w}_S) + \mu\mathrm{w}_S\right) - \\
-\frac{\beta}{4}\left((\mathrm{w}_N{}^2 - \mathrm{w}_S{}^2) + \mu\mathrm{w}_S{}^2\right) &> F
\end{aligned} \tag{3.18}$$

Lower wages in the South and higher wages in the North are an important cause for offshoring but these are not the only decision factors when it comes to offshoring. For a given wage gap between the two countries, weaker IPR (a higher probability of imitation μ) in the destination country and a higher fixed cost required by the participation in the joint venture will provide a lower incentive for collaboration. If the inequality holds as equality, then the Northern Firm is indifferent between creating a joint venture and performing R&D at home.

A Northern Firm will choose to buy R&D from the South over performing R&D at home if:

$$
\begin{gathered}
\pi_{BUY} > \pi_H \\
(1-\gamma)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_S}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) > \\
> \frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_N}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_N}^2\beta}{4} - \frac{\mathrm{w}_N\varepsilon}{2} \\
-\frac{\gamma\alpha}{2\beta}(\frac{\alpha}{2} + \varepsilon) + (\frac{\alpha+\varepsilon}{2})((\mathrm{w}_N - \mathrm{w}_S) + \gamma \mathrm{w}_S) - \\
-\frac{\beta}{4}(({\mathrm{w}_N}^2 - {\mathrm{w}_S}^2) + \gamma {\mathrm{w}_S}^2) > 0
\end{gathered} \tag{3.19}
$$

Buying R&D from the South allows the Northern firm to avoid paying the fixed cost of a joint venture, but the firm will face a higher risk of imitation. For a given wage gap between the two countries, weaker IPR (a higher probability of imitation γ) in the destination country will provide a lower incentive for collaboration. If the inequality holds as equality, then the Northern Firm is indifferent between buying R&D from the South and performing R&D at home.

A Northern Firm will choose to create a joint venture over buying R&D from the South if:

$$
\begin{gathered}
\pi_{JV} > \pi_{BUY} \\
(1-\mu)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_S}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) - F > \\
> (1-\gamma)\left(\frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{{\mathrm{w}_S}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}\right) \\
(\gamma-\mu)[\frac{1}{2}(\alpha+\varepsilon)(\frac{\alpha}{\beta} - \mathrm{w}_S) + \frac{{\mathrm{w}_S}^2\beta}{4}] > F
\end{gathered} \tag{3.20}
$$

When the two offshoring strategies face the same risk of imitation, the Northern firm will prefer to buy the R&D from the South (if it gives higher profits than doing research at home) because it avoids paying the fixed costs associated with joint venture. If the inequality holds as equality, then the Northern Firm is indifferent between creating a joint venture and buying R&D from the South. In order for a joint venture to exist, the risk of imitation when buying the R&D (γ) has to be bigger than the risk of imitation when creating a joint venture (μ).

To illustrate the connection between the theoretical model and the estimations we rewrite the profits of each one of the three alternatives (perform R&D at home, buy R&D from a Southern firm or form a joint venture with a Southern firm) in the following form:

$$\begin{aligned}
\pi_H &= \frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_N}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_N{}^2\beta}{4} - \frac{\mathrm{w}_N\varepsilon}{2} = \\
&= \frac{\alpha^2}{4\beta} - \frac{\alpha}{2}\mathrm{w}_N + \frac{\beta}{4}\mathrm{w}_N{}^2 + (\frac{\alpha}{2\beta} - \frac{\mathrm{w}_N}{2})\varepsilon = \\
&= \frac{\alpha^2}{4\beta}Z_{0H} - \frac{\alpha}{2}Z_{1H} + \frac{\beta}{4}Z_{2H} + \varepsilon_H = \\
&= Z_H\Phi_H + \varepsilon_H \qquad (3.21)
\end{aligned}$$

Where $Z_H = (Z_{0H}, Z_{1H}, Z_{2H}, Z_{3H}) = (1, \mathrm{w}_N, \mathrm{w}_N{}^2, \mathrm{F})$ and $\Phi_H = (\frac{\alpha^2}{4\beta}, -\frac{\alpha}{2}, \frac{\beta}{4}, 0)$

Likewise, the profits of a Northern firm forming a joint venture with a Southern firm can be written:

$$\begin{aligned}
\pi_{JV} &= (1-\mu)(\frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_S{}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}) - F = \\
&= \frac{\alpha^2}{4\beta}(1-\mu) - \frac{\alpha}{2}\mathrm{w}_S(1-\mu) + \frac{\beta}{4}\mathrm{w}_S{}^2(1-\mu) - F + (\frac{\alpha}{2\beta} - \frac{\mathrm{w}_S}{2})\varepsilon(1-\mu) = \\
&= \frac{\alpha^2}{4\beta}Z_{0JV} - \frac{\alpha}{2}Z_{1JV} + \frac{\beta}{4}Z_{2JV} - FZ_{3JV} + \varepsilon_{JV} = \\
&= Z_{JV}\Phi_{JV} + \varepsilon_{JV} \qquad (3.22)
\end{aligned}$$

Where $Z_{JV} = (Z_{0JV}, Z_{1JV}, Z_{2JV}, Z_{3JV}) = (1-\mu, \mathrm{w}_S(1-\mu), \mathrm{w}_S{}^2(1-\mu), \mathrm{F})$ and $\Phi_{JV} = (\frac{\alpha^2}{4\beta}, -\frac{\alpha}{2}, \frac{\beta}{4}, -1)$

At last, in the case of buying R&D from a Southern firm the Northern profits can be written:

$$\begin{aligned}
\pi_{BUY} &= (1-\gamma)(\frac{\alpha^2}{4\beta} - \frac{\alpha \mathrm{w}_S}{2} + \frac{\alpha\varepsilon}{2\beta} + \frac{\mathrm{w}_S{}^2\beta}{4} - \frac{\mathrm{w}_S\varepsilon}{2}) = \\
&= \frac{\alpha^2}{4\beta}(1-\gamma) - \frac{\alpha}{2}\mathrm{w}_S(1-\gamma) + \frac{\beta}{4}\mathrm{w}_S{}^2(1-\gamma) + (\frac{\alpha}{2\beta} - \frac{\mathrm{w}_S}{2})\varepsilon(1-\gamma) = \\
&= \frac{\alpha^2}{4\beta}Z_{0BUY} - \frac{\alpha}{2}Z_{1BUY} + \frac{\beta}{4}Z_{2BUY} + \varepsilon_{BUY} = \\
&= Z_{BUY}\Phi_{BUY} + \varepsilon_{BUY} \qquad (3.23)
\end{aligned}$$

Where $Z_{BUY} = (Z_{0BUY}, Z_{1BUY}, Z_{2BUY}, Z_{3BUY}) = (1-\gamma, \mathrm{w}_S(1-\gamma), \mathrm{w}_S{}^2(1-\gamma), \mathrm{F})$ and $\Phi_{BUY} = (\frac{\alpha^2}{4\beta}, -\frac{\alpha}{2}, \frac{\beta}{4}, 0)$

Given the above-mentioned profit functions, a Northern firm's choice probability for forming a joint venture is:

$$q_{JV} = Pr[Z_{JV}\Phi_{JV} + \varepsilon_{JV} > Z_j\Phi_j + \varepsilon_j; j \neq JV] \qquad (3.24)$$

When a Northern firm chooses to form a joint venture, this probability is higher than the probability of any other alternative.

If we assume that the error term are distributed with the extreme value distribution, the choice probability to form a joint venture is:

$$q_{JV} = \frac{e^{Z_{JV}\Phi_{JV}}}{e^{Z_H\Phi_H} + e^{Z_{BUY}\Phi_{BUY}} + e^{Z_{JV}\Phi_{JV}}} \qquad (3.25)$$

Applying the log-odds transformation relative to the alternative of buying R&D from a Southern firm yields:

$$\ln\left(\frac{q_{JV}}{q_{BUY}}\right) = \ln\left(\frac{e^{Z_{JV}\Phi_{JV}}}{e^{Z_{BUY}\Phi_{BUY}}}\right) = (Z_{JV}\Phi_{JV} - Z_{BUY}\Phi_{BUY}) + u \qquad (3.26)$$

where $u = \varepsilon_{JV} - \varepsilon_{BUY}$.

Assuming that

$$E(u|Z_{JV}, Z_{BUY}) = 0 \tag{3.27}$$

the log-odds transformation becomes the linear mean regression model

$$E\left(\ln\left(\frac{q_{JV}}{q_{BUY}}\right)|Z_{JV}, Z_{BUY}\right) = Z_{JV}\Phi_{JV} - Z_{BUY}\Phi_{BUY} \tag{3.28}$$

Likewise, the log-odds transformation of the probability to form a joint venture relative to the alternative of home production yields:

$$E\left(\ln\left(\frac{q_{JV}}{q_{H}}\right)|Z_{JV}, Z_{H}\right) = Z_{JV}\Phi_{JV} - Z_{H}\Phi_{H} \tag{3.29}$$

And last, the log-odds transformation of buying R&D from a Southern firm relative to the alternative of home production yields:

$$E\left(\ln\left(\frac{q_{BUY}}{q_{H}}\right)|Z_{BUY}, Z_{H}\right) = Z_{BUY}\Phi_{BUY} - Z_{H}\Phi_{H} \tag{3.30}$$

The choice between each one of the three alternatives (perform R&D at home, buy R&D from a Southern firm or form a joint venture with a Southern firm) depends on the Northern wage, Southern wage, the fixed cost of establishing a joint venture and the demand for the product. In the empirical part I only observe the two offshoring strategies. Given how the risk of imitation was defined in this paper and if we ignore the fixed cost of establishing a joint venture, a Northern firm will always prefer to form a joint venture over buying R&D from the South. Once we take into account the fixed cost, a Northern firm might prefer to buy the R&D from the South because it avoids paying the fixed costs associated with joint venture.

3.4 Data and Estimation

In order to test the conclusions of the theoretical model, in this section I look at the determinants of international partnership in 89 countries over the period 1990 to 2009. The data set used in the paper is from the SDC Platinum database. This dataset provides partnership information like: company information (e.g., name, nationality, ownership), a description of the purpose of partnership, nationality and ownership stake in the new entity (in the case of a joint venture). The previous data set is appended with information about wages. This information was collected from the Yearbook of Labour Statistics and The International Yearbook of Industrial Statistics. The Ginarte and Park index is used to measured the strength of intellectual property rights protection across countries. The exchange rates and the GDP deflator came from the IMF database. The cost of doing business is a measure of the fixed costs required to start a business in a certain country, and it is reported by The World Bank Group starting in 2004.

Each partnership has one or more of the following objectives: - manufacturing services (27%); - marketing services (26%); - licensing services (7%); - research & development services (20%); - funding services (2%); - software development services (0%); - advertising services (1%); - retail & wholesale services (14%); - health& development service (3%);

The dependent variable represents the choice of the partnership type. It was defined as follows:

=1 if the relationship involved equity participation (joint venture)

=0 if there was no equity involved (pure contracts)

The estimation method is a binomial logit analysis where the independent variables are defined as follows:

IPR protection in the destination country. The measure of a country intellectual property rights protection is based on the information found in Ginarte and Park (1997).

Wage gap. This ratio measures the difference in the hourly wages (denominated in USD) across participating countries in a partnership.

Wage gap squared. Based on the model presented in Section 3.3, the wage gap affects a firm's organizational decision nonlinearly. A negative sign means that the effect of additional units of wage gap on firm's decision to form a joint venture become increasingly smaller.

Cost of doing business. This measures the number of days required in order to start a business in a country in a certain year. This index is reported by The World Bank Group starting in 2004. For the first part of the estimations, the 2004 value for each country is considered to be the value for the previous years as well.

Two of the above mentioned variables are not a perfect fit for what I want to describe. The Yearbook of Labour Statistics and the International Yearbook of Industrial Statistics collected data on wages from different types of sources: labor-related establishment census, administrative records, industrial or commercial survey, insurance records, etc. These sources were not always disaggregated enough to measure only the wages in the pharmaceutical industry. The second variable in question is the cost of doing business. The number of days required in order to start a business is not the best measure for the fixed cost of establishing a new business in a country.

Not all the above explanatory variables are included in each Z's. But when we calculate the log-odds transformation of the probability to form a joint venture relative to the alternative of buying R&D from a Southern firm, they all appear as explanatory variables.

The first hypothesis of the theoretical model was that the preference of a company for extra control (forming a joint venture rather than a contractual collaboration) is inversely related with the level of IPR protection. Consistent with this hypothesis, the results presented in Table I.3 column (1) indicate that the preference of companies for extra control, through a joint venture mode for international partnering, is inversely related to the strength of intellectual property rights protection in the home country of their partner. A large IPR measure denotes strong IPR protection in the destination country. In this case the company will opt for a contract. Looking at the size of the coefficient for the constant term and comparing it to the coefficient for the IPR protection it seems that the level of IPR protection has a significant influence over the decision to form a joint venture or to sign a contractual partnership. In the case of logit estimation it is difficult to interpret the coefficients (except for the sign). To get a better understanding of the effects of IPR protection on the form of partnership I calculated the marginal effects.

In the logit regression models, the marginal effect is the slope of the probability curve relating changes in one independent variable to Pr(JV=1;Z), holding all other variables constant. Marginal effects provide a good approximation to the amount of change in the dependent variable that will be produced by a 1-unit change in a specific independent variable. In this case a 1-unit increase in the level of IPR protection leads to a .2 decrease in the probability of forming a joint venture.

A second hypothesis of the theoretical model was that the preference of a company for extra control (forming a joint venture rather than a contractual collaboration) is inversely related with the wage gap between the two countries. The results indicate a smaller but significant effect on the decision of firms to have more control and create a joint venture. Looking at the marginal effect, a 1-dollar increase in the wage gap leads to a .01 decrease in the probability of forming a joint venture.

A third hypothesis of the model is that the fixed costs of establishing a joint venture act as a deterrent to forming a joint venture. I employ the index called "the cost of doing business" as a proxy for this fixed cost. Unfortunately the data covering this index starts in 2004. To keep the previous years in my analysis I assumed that the 2004 value is the correct value for the previous years. The results are presented in Table I.3 column (2). The results indicate a significant effect on the decision of firms to have more control and create a joint venture. This result supports the third hypothesis of the theoretical model was that the preference of a company for extra control (forming a joint venture rather than a contractual collaboration) is inverse related with the fixed cost of establishing a business in that country. Looking at the marginal effect, a 1-day increase in the number of days required to start a new business leads to a .004 decrease in the probability of forming a joint venture. The wage gap kept its sign.

To account for other country specific elements that might influence the decision to form a joint venture I introduce dummy variables for each country. The results of this estimation are presented in Table I.3 column (3). Out of the total 11718 observations, 33 observations are dropped because they perfectly predict success or failure (this is the case for small countries that have one observation). The international wage ratio becomes statistically insignificant but the sign stays the same. The influence of IPR protection and the Cost of doing business in the destination remain significant but with a lower magnitude. For the next estimation I introduce dummy variables for each year along with the country dummies. The results of this estimation are presented in Table I.3 column (4).

To further assess the fit of the most complete model (the specification which includes the cost of doing business variable and the dummy variables for countries and years) I assigned to each observation one of the two outcomes of the dependent variable. A positive outcome was assigned when the model predicted a probability of more than 0.5, and a negative outcome was assigned if the probability was less than 0.5. The results presented in Table I.4 show a relatively good fit of the model. In Table I.4, the first row within a cell measures frequency, the second row column percentage and the third cell percentage.

International collaboration is not limited to manufacturing or marketing but it also includes research and development. When a firm decides to offshore part of its R&D activity to a different country, the IPR protection in the destination country is an important concern (which might not be the situation in the case of marketing offshoring). But the property rights aspect of the R&D activity is not the only element that might influence the organizational choice of an offshoring firm. In a recent paper by Pol Antras (2003) it has been suggested that firms choose to form joint ventures in order to take advantage of transfer-pricing opportunities in countries with less taxation. This is especially true in the case of R&D activity when government authorities would have a hard time to find a similar arm's length contract to compare with the joint venture contract and decide whether or not the price paid for a certain R&D service was overinflated. To see whether or not this hypothesis is important I included an R&D dummy in my estimations.

Table I.5 presents the results of the previous estimations, now including an R&D dummy. Across the four specifications, the results are consistent with the first hypothesis of the theoretical model, that the preference of a company for extra control (forming a joint venture rather than a contractual collaboration) is inversely related with the level of IPR protection. The second hypothesis of the theoretical model (that the preference of a company for extra control is inversely related with the wage gap between the two countries) is also consistent with the results from the first two specifications. The results in Table I.5, column (2) support the third hypothesis of the theoretical model, that the preference of a company for extra control is inversely related with the fixed cost of establishing a business in that country.

Looking at the size of the coefficient for the R&D dummy it seems that the nature of the collaboration has a significant influence over the decision to form a joint venture or to sign a contractual partnership. For a given level of intellectual protection in the destination country, firms that offshore the R&D activity have a stronger incentive to form a joint venture and maintain a certain control over the operation than firms that offshore other types of collaboration. This result confirms the importance of the type of collaboration over the organizational structure of offshoring whether it is because of property rights concerns or transfer-pricing opportunities.

To account for other country-specific elements that might influence the decision to form a joint venture I introduce dummy variables for each country. The results of this estimation are presented in Table I.5 column (3). The international wage ratio becomes statistically insignificant. The influence of IPR protection and the Cost of doing business in the destination remain significant but with a lower magnitude. For the next estimation I introduce dummy variables for each year along with the country dummies. The results of this estimation are presented in Table I.5 column (4). The results are very similar with the previous estimation.

To assess further the fit of the most complete model I assigned to each observation one of the two outcomes of the dependant variable. A positive outcome was assigned when the model predicted a probability of more than 0.5, and a negative outcome was assigned if the probability was less than 0.5. The results presented in Table I.6 show a relatively good fit of the model.

The Model presented in Section 3.3 includes the variable "Wage Gap squared". To see whether the wage gap affects a firm's organizational decision nonlinearly I should have included the wage gap squared as an independent variable in my regression. The high correlation (.915) between the variables "Wage Gap" and "Wage Gap squared" is the reason why I didn't introduce the variable "Wage Gap squared" in my previous estimations. In order to test the opportunity of introducing the "Wage Gap squared" in my estimations I included this variable in Table I.7 and I.8. According to the results presented in Table I.7 column (1), the effect of IPR protection remains significant at a 5% level while wages keep the same sign but their significance decreased to a 15% level. The negative sign for the coefficient of wage gap squared means that the effect of additional units of wage gap on firm's decision to form a joint venture become increasingly smaller. For nested models (in my case the specification in Table I.7 column 1 is the full specification while the null specification is presented in Table I.3 column 1) we can use the likelihood ratio test to determine whether the addition of more independent variables achieves a significant increase in the explanatory power compared with a null model with fewer independent variables. The chi-squared test statistic is small (LR chi2(1)=2.48) indicating only a very small increase in the explanatory power. The probability of receiving a χ^2 value of 2.48 or higher in the sample is relatively big when the Wage Gap squared coefficient is zero. In this case we can be fairly certain that the Wage Gap squared coefficient is zero.

Using the likelihood ratio test to compare the full specification in Table I.7 column 2 with the null specification from Table I.3 column 2, we find a small chi-squared test statistic (LR χ^2 (1)=17.30) but the probability of receiving this value or higher is very small. In this case we can say that the Wage Gap squared coefficient is not zero. Locking at the results in Table I.7 column 1, the introduction of the Wage Gap squared variable results in a change of sign for the coefficient on the Wage Gap. The introduction of country dummies (Table I.7 column 3) and time dummies (column 4) reverts the sign for the coefficient on the Wage Gap to negative. However the effect is not statistically significant. The likelihood ratio test for the models presented in Table I.7 column 3 and 4 (compared with the results in Table I.3) show very small test statistics (LR chi2(1)=.27 and .19 respectively) which indicates a very small increase in the explanatory power following the introduction of the Wage Gap squared variable.

The results presented in Table I.8 followed the pattern discuss for the Table I.7. The introduction of both the Wage gap squared and the Cost of doing results in a change of sign for the coefficient on the Wage Gap.

3.5 Conclusions

In exploring the conditions leading to international offshoring under incomplete contracts, new models explained trade based on differences in endowments of factors across countries and monopolistic competition arising from consumer demand for variety. Some of the papers analyzing the choice between vertical integration and arm's length contracting used a property rights approach (like Antras (2003) and Antras and Helpman (2004)) that emphasizes that ownership and control should be allocated so as to minimize the loss in surplus due to investment distortions. Thus if two agents each make an investment relevant to a different dimension of the business, ownership should be given to just one of the agents (vertical integration), or the two dimensions of the business should be separated (non-integration or outsourcing), depending on which arrangement minimizes the loss in surplus. Another approach was the incentive systems employed by the Grossman and Helpman (2002, 2004). This approach involves optimal incentive contracts designed by a principal to induce investment or effort by managers. My paper looks at how institutions (the property rights protection in a country), the enforcement of contracts in a foreign country, the cost of doing business in that country and the wage gap between countries are explanations for different international offshoring strategies.

Regarding the choice of offshoring strategy, the outcomes vary based on differences between the intensity of intellectual property rights, the cost of starting a business in a country and the wage gap between North and South. The theoretical model shows how weak IPR protection in the destination country provides incentive to form a joint venture and maintain a better control over the collaboration. Stronger IPR combined with lower costs of establishing a joint venture stimulate contracts at arm's - length. A big wage gap between North and South might offset the risk of imitation and provide sufficient incentives for firms investing in countries with weak IPR protection to forgo the option of joint ventures and pursue contracts at arm's - length.

On the empirical side, the estimation shows that international intellectual property rights protection is a significant factor for companies to consider when engaging in international partnerships. When companies find themselves in an environment with less secure intellectual property rights protection, they tend to choose joint ventures rather than contractual partnerships. The wage gap between countries and the cost of doing business have a negative effect on the preference for international joint ventures and the fixed costs of establishing a joint venture act as a deterent to forming a joint venture, as expected. The R&D activity has a significant influence over the organizational structure of offshoring. Firms engaging in R&D offshoring have a greater incentive to form joint ventures than firms offshoring other activities. This can be due to property rights concerns related to leakage of information in countries with weak IPR protection or it might be the case that firms choose to form joint venture in order to take advantage of transfer pricing opportunities in countries with less taxation.

In looking to the future, first I would be focusing on improving my measures for wages and the costs of doing business. I would also be interested in paying greater attention to the types of transaction costs observed in international arms length contracts, including the costs of ensuring payment across international borders. The second direction would be to extend my analysis to other types of international cooperations: mergers and acquisitions. The SDC Platinum database has a collection on mergers and acquisitions that wold complement perfectly my data on joint-ventures and arm's-length contracts. The third direction would be to do a two-stage estimation that would account for the anticipated willingness of firms to do R&D in a joint venture.

Appendix A

Calculations for Chapter 1

In this annex, I present the calculations behind the differential equations describing the equilibrium.

Let $\zeta = \frac{n_N}{n}$.

$$\dot{\zeta}/\zeta = \frac{\dot{n}_N}{n_N} - \frac{\dot{n}}{n} = \frac{\dot{n} - \dot{n}_s}{n_N} - \frac{\dot{n}}{n} = \frac{\dot{n}}{n_N} - \frac{\dot{n}_s}{n_N} - \frac{\dot{n}}{n} = \frac{g}{\zeta} - m - g$$

$$\dot{\zeta} = g - (g + m)\zeta$$

In the North: $E_N = p_N n_N x_N$

$$\frac{\dot{E}_N}{E_N} = -\frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + g + \frac{\dot{v}_N}{v_N}$$

$$\frac{\pi_N}{v_N} = \frac{1-\alpha}{\alpha \mathrm{a}_N} \frac{L_N - \mathrm{a}_N g}{\zeta}$$

$$\dot{g} = [(L_N/\mathrm{a}_N - g)]\,[\rho + m + g - (1/\alpha - 1)(L_N/\mathrm{a}_N - g)/\zeta]$$

In the South:

$$\frac{\dot{n}_S}{n_S} = m\frac{\zeta}{1-\zeta}$$

The resource constraint becomes:

$$n_S x_S = L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}$$

Since $p_S = \frac{w_S}{\alpha}$ and $v_S = w_S(1+k)\mathrm{a}_S/n_S$, then

$$p_S = \frac{v_S n_S}{\alpha(1+k)\mathrm{a}_S}$$

and therefore

$$\dot{p}_S = \frac{1}{\alpha(1+k)\mathrm{a}_S}(\dot{v}_S n_S + v_S \dot{n}_S)$$

$$\frac{\dot{p}_S}{p_S} = \frac{\dot{v}_S}{v_S} + \frac{\dot{n}_S}{n_S} = \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta}$$

$$E_S = p_S n_S x_S = p_S(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta})$$

$$\begin{aligned}\dot{E}_S &= \dot{p}_S\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right) - p_S\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta} - \frac{p_S m(1+k)\mathrm{a}_S\dot{\zeta}}{(1-\zeta)^2} = \\ &= \dot{p}_S\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right) - p_S\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta} - \frac{p_S m(1+k)\mathrm{a}_S[g-(g+m)\zeta]}{(1-\zeta)^2} =\end{aligned}$$

$$\frac{\dot{E}_S}{E_S} = \frac{\dot{p}_S}{p_S} - \frac{\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S[g-(g+m)\zeta]}{\zeta(1-\zeta)\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)}$$

$$\frac{\dot{E}_S}{E_S} = \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta} - \frac{\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S[g-(g+m)\zeta]}{\zeta(1-\zeta)\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)}$$

$$r - \rho = \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta} - \frac{\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S[g-(g+m)\zeta]}{\zeta(1-\zeta)\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)}$$

$$\begin{aligned}\pi_S = \left(\frac{1}{\alpha}-1\right)w_S x_S = \left(\frac{1}{\alpha}-1\right)\frac{v_S n_S x_S}{(1+k)\mathrm{a}_S} = \\ = \frac{1-\alpha}{\alpha}\frac{v_S n_S}{(1+k)\mathrm{a}_S}\frac{1}{n_S}\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)\end{aligned}$$

$$\pi_S/v_S + \dot{v}_S/v_S = r$$

$$\frac{1-\alpha}{\alpha}\frac{1}{(1+k)\mathrm{a}_S}\left(L_S - m(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}\right)\frac{\dot{v}_S}{v_S} = r$$

It follows that:

$$\frac{1-\alpha}{\alpha}\frac{1}{(1+k)\mathrm{a}_S}\left(L_S-\frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}\right)\frac{\dot{v}_S}{v_S}-\rho=$$

$$=\frac{\dot{v}_S}{v_S}+m\frac{\zeta}{1-\zeta}-\frac{\dot{m}(1+k)\mathrm{a}_S\frac{\zeta}{1-\zeta}}{L_S-\frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}}-\frac{m(1+k)\mathrm{a}_S[g-(g+m)\zeta]}{\zeta(1-\zeta)\left(L_S-\frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}\right)}$$

$$\dot{m}=\frac{1-\zeta}{\zeta}\left[\rho+m\frac{\zeta}{1-\zeta}-\frac{1-\alpha}{\alpha}\frac{1}{(1+k)\mathrm{a}_S}\left(L_S-\frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}\right)\right]\frac{L_S-\frac{m(1+k)\mathrm{a}_S\zeta}{1-\zeta}}{(1+k)\mathrm{a}_S}-$$

$$-\frac{m}{(1-\zeta)\zeta}\left[g-(m+g)\zeta\right]$$

Appendix B

Tables for Chapter 1

Table B.1: Description of variables

Variables	Definition
EU patents	The number of patent applications filled in the European Union (based on a dataset maintained by the European Patent Office). My innovation measure.
Indian patents	The number of patent applications filled in India (based on a dataset maintained by the Technology Information, Forecasting and Assessment Council)
Indian - EU patents	The difference between the number of patent applications filled in India and the number of EU patent applications. My imitation measure
Experience	This is the previous number of years for which data was reported.
Employees	The total number of employees employed in a company is reported here.
Wages	This includes total expenses incurred by an enterprise on all employees, including the management. Besides salaries and wages, items such as payment of bonus, contribution to employee's provident fund and staff welfare expenses are also included under wages.
Individual wages	This is the ratio of wages to employees.
R&D	These are the revenue and capital expenses incurred by companies on research and development.
Export services	This includes those export earnings which are through the sale of services outside the country. My offshoring measure.
Total exports	This is the total revenue earned from exports of goods and services. Income earned in foreign currency by way of interest, dividend, royalties, and consultancy fees is also included here. Foreign exchange earnings from tourism/air services are also included in the total export earnings. Exports of goods are usually in free on board value. Deemed export sales are included in total exports.

Import capital	This is value of imported capital goods like plant and machinery, goods etc.
Sales	Sales generated by a firm from its main business activity measured by charges to customers for goods supplied and services rendered. Excludes income from activities not related to main business, such as dividends, interest, and rents in the case of industrial firms, as well as non-recurring income.
Assets	Gross fixed assets of a firm, which includes movable and immovable assets as well as assets which are in the process of being installed.
Net profits	This is the excess amount of income over all expenses.
Return on Assets	Ratio of Net Profits to Assets in a firm, averaged across firms in that industry.
Private firms	Firms majority-owned by a business group and private firms.
Foreign firms	Firms incorporated overseas.
Foreign	This is a dummy variable that takes value one if the firm was incorporated overseas.
Relative price	The relative price is a weighted average of the top eight Northern export destinations for Indian products divided by the Indian price. These are Industrial Product Price Index for Drugs and pharmaceuticals (SIC 3-digit level) from U.S.A., Canada, France, Germany, Italy, U.K., Sweden and Switzerland.The weights are calculated as exports towards an individual destination relative to all eight destinations, for each year. Prices are also converted to Indian Rupees.
Interest rate	The interest rate on Central State (India) dated securities is used as a measure for the interest rate.

Data is in constant Rs. Crore (10 Million Rupees), deflated by Wholesale Price Index (for all goods) from the Office of The Economic Advisor (base year 1997).

Table B.2: Summary statistics

Variable	Mean	Std. dev.	Min.	Max.
Innovation (EU patents)	3.970621	25.22654	0	328
Indian patents	2.041243	6.823693	0	143
Imitation (Indian - EU patents)	.9786723	3.155789	0	52
R&D Offshoring (Services exported)	.4320454	3.452941	0	99.61184
Relative price	19.55	3.024697	14	27
Interest rate	10.609	2.363711	5.71	13.75
Total Assets	82.78826	224.1568	.0068823	3688.787
Individual wages	.0042063	.0043981	.0001070	.0339108
Total Exports	17.66706	79.25586	0	1500.5
Total R&D	2.94509	11.50069	0	327.023
Imported capital	2.663106	7.32123	0	93.99259
Sales	70.36692	166.8117	0	3276
Net profits	6.486414	30.65071	-233.7302	660.54
Experience	3.771455	4.822738	0	19
Foreign dummy	.0960452	.294673	0	1

Table B.3: Industrial Composition - Average Number of Firms

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	169	291	283	220
Foreign	23	33	26	17
Full sample	192	324	309	237

Table B.4: Industrial Composition - Average Total Assets

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	45.17886	55.97186	75.50408	151.9184
Foreign	76.02136	85.13052	125.4428	273.2017
Full sample	51.08994	58.5602	79.5278	161.6565

Table B.5: Industrial Composition - Average Total Sales

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	53.24281	41.14832	63.37358	105.6982
Foreign	137.0886	135.3756	147.4721	213.9474
Full sample	69.28436	49.4707	70.12548	114.3792

Table B.6: Industrial Composition - Average Profits (Net Profits)

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	2.339798	1.943105	5.623154	15.04067
Foreign	5.062124	11.16114	16.27654	42.6501
Full sample	2.860738	2.757346	6.47846	17.15138

Table B.7: Industrial Composition - Return on Assets

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	5.37089	.51007	.21011	7.91716
Foreign	8.06275	1.56736	10.94584	11.90998
Full sample	5.80	1.4593	1.07912	8.22891

Table B.8: Industrial Composition - Fraction of Total Number of Firms

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	88%	90%	92%	93%
Foreign	12%	10%	8%	7%

Table B.9: Industrial Composition - Fraction of Total Assets

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	81%	85%	87%	88%
Foreign	19%	15%	13%	12%

Table B.10: Industrial Composition - Fraction of Total Sales

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	74%	73%	82%	86%
Foreign	25%	27%	18%	14%

Table B.11: Industrial Composition - Fraction of Total Net Profits

	I 1989 - 1994	II 1995 - 2000	III 2001 - 2004	IV 2005 - 2008
Domestic	77%	61%	79%	82%
Foreign	23%	39%	21%	18%

Table B.12: Fixed Effects Estimation Results

	Innovation (EU patents) (19)	(19')	Imitation (Indian-EU pat.) (20)	(20')	R&D offshoring (exp. serv.) (21)	(21')
Year 1995-2000 (dummy)	2.287748** (.7914169)	.2367076** (.0216222)	.156781 (.1991568)	.1339665** (.0271944)	-.1873866 (.1769639)	.0447108** (.0178409)
Year 2001-2004 (dummy)	1.643543 (1.221752)	.3422859** (.0302257)	.0312482 (.3074488)	.129913** (.038015)	-.2386413 (.2731875)	.0987572** (.0249097)
Year 2005-2008 (dummy)	.2815808 (1.68335)	.4883179** (.0415451)	-1.949215** (.423608)	-.1580306** (.0522514)	-.0841127 (.376389)	.1820645** (.034183)
Rel. price (1 year lag)	.1950361** (.0673185)	.0428999 (.0456215)	-.0574432** (.0169404)	-.2735137** (.0573784)	-.0058506 (.0150523)	.015541 (.0376727)
Interest rate (1 year lag)	.132504 (.1485588)	-.0927159* (.0469895)	.1522988 (.0373842)	.1422935** (.0590989)	.0717238** (.0332144)	.0297309 (.0388003)
Total Assets	-.00645** (.0019833)	.0318248** (.01174)	-.000978** (.0004991)	.0320612** (.0147655)	-.0038842** (.000437)	.0428884** (.0096703)
Individual wage	795.5617** (119.4741)	38.94711** (3.78737)	-36.30721 (30.06516)	-2.345278 (4.763391)	-4.001243 (26.60948)	39.10331** (3.064134)
Total exports	-.0180426** (.0055343)	.0785909** (.0089031)	-.0013805 (.0013927)	.05016** (.0111975)	.0439668** (.0010897)	.1049378** (.0071572)
Total R&D	.4849346** (.0294069)	.3427687** (.019406)	.0880225** (.0074001)	.0129023 (.0244069)		
Experience	.3889495** (.1143942)	-.0644516** (.0132565)	.2130052 (.0287868)	.10943** (.0166727)	.0475079* (.0255785)	-.0464485** (.0109217)
Foreign firm (dummy)	2.34255 (6.946752)	2.583548** (.336376)	-4.20778** (1.748122)	-1.613139** (.4230615)	-1.211653 (2.410489)	-.8441382** (.2774447)
Number of obs.	4254	4253	4254	4253	4253	4253
Adj R-squared	0.9004	0.9147	0.5862	0.7639	0.5781	0.6247

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Table B.13: Factors that affect the probability of moving from imitation to innovation over time (as measured by the ratio of EU patents/Total patents)

Rel. price	Interest rate	Total assets	Total exports	Total R&D	Individual wages	Net profits	Experience
-.0723939	.2340278**	.0013366	-.0101407*	.0559128	-14.34781	.020734	.7698514**
(.0478573)	(.079366)	(.0018722)	(.0060315)	(.048113)	(88.92997)	(.0138292)	(.0744853)
1238	obs.						

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Table B.14: Fixed Effects Estimation Results with fixed firm designation

	Innovation (EU patents) (19)	(19')	Imitation (Indian-EU pat.) (20)	(20')	R&D offshoring (exp. serv.) (21)	(21')
Year 1995-2000	2.287748**	.2367076	.156781	.1339665**	-.1873866	.0447108**
(dummy)	(.7914169)	(.0216222)	(.1991568)	(.0271944)	(.1769639)	(.0178409)
Year 2001-2004	1.643543	.3422859**	.0312482	.129913**	-.2386413	.0987572**
(dummy)	(1.221752)	(.0302257)	(.3074488)	(.038015)	(.2731875)	(.0249097)
Year 2005-2008	.2815808	.4883179**	-1.949215**	-.1580306**	-.0841127	.1820645**
(dummy)	(1.68335)	(.0415451)	(.423608)	(.0522514)	(.376389)	(.034183)
Rel. price	.1950361**	.0428999	-.0574432**	-.2735137**	-.0058506	.015541
(1 year lag)	(.0673185)	(.0456215)	(.0169404)	(.0573784)	(.0150523)	(.0376727)
Interest rate	.132504	-.0927159**	.1522988**	.1422935**	.0717238**	.0297309
(1 year lag)	(.1485588)	(.0469895)	(.0373842)	(.0590989)	(.0332144)	(.0388003)
Total Assets	-.00645**	.0318248**	-.000978**	.0320612**	-.0038842	.0428884**
	(.0019833)	(.01174)	(.0004991)	(.0147655)	(.000437)	(.0096703)
Individual wage	795.5617**	38.94711**	-36.30721	-2.345278	-4.001243	39.10331**
	(119.4741)	(3.78737)	(30.06516)	(4.763391)	(26.60948)	(3.064134)
Total exports	-.0180426**	.0785909	-.0013805	.05016	.0439668**	.1049378**
	(.0055343)	(.0089031)	(.0013927)	(.0111975)	(.0010897)	(.0071572)
Total R&D	.4849346**	.3427687	.0880225**	.0129023		
	(.0294069)	(.019406)	(.0074001)	(.0244069)		
Experience	.3889495**	-.0644516**	.2130052**	.10943**	.0475079*	-.0464485**
	(.1143942)	(.0132565)	(.0287868)	(.0166727)	(.0255785)	(.0109217)
Foreign firm	29.1058**	1.8489	-4.12485	.1236368	.8689168	1.874231**
(dummy)	(10.78201)	(.3796388)	(2.713248)	(.4774733)	(2.718789)	(.312058)
Imitator	27.36115**	2.000471**	1.009848	1.088741**	.8329102	1.826617**
(dummy)	(12.24264)	(.3701542)	(3.080809)	(.4655444)	(2.675897)	(.304263)
Switch firm	22.03448*	1.940606**	3.123761	1.528688**	1.056727	1.866868
(dummy)	(11.34781)	(.3510905)	(2.855629)	(.4415679)	(2.536691)	(.2883776)
Innovator	93.77743**	5.725144**	-1.958092	.0011659	1.454485	1.949723**
(dummy)	(11.21997)	(.3474384)	(2.823459)	(.4369747)	(2.508198)	(.2852031)
Number of obs.	4254	4253	4254	4253	4253	4253
Adj R-squared	0.9004	0.9147	0.5862	0.7639	0.5781	0.6247

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Table B.15: Fixed Effects Estimation Results without Individual Wages

	Innovation (EU patents) (19)	(19')	Imitation (Indian-EU pat.) (20)	(20')	R&D offshoring (exp. serv.) (21)	(21')
Year 1995-2000 (dummy)	2.216552** (.7957352)	.2541275** (.0218438)	.1600302 (.1991503)	.1329175** (.0271082)	-.1870402 (.1769267)	.064802** (.0181368)
Year 2001-2004 (dummy)	1.461388 (1.228222)	.3823757** (.0303737)	.0395613 (.3073899)	.1274989** (.0376938)	-.2377343 (.2730867)	.1448216** (.0251537)
Year 2005-2008 (dummy)	.0991272 (1.692465)	.5499022** (.0416605)	-1.940888** (.4235768)	-.1617391** (.0517007)	-.0832436 (.3762974)	.2540963** (.0344072)
Rel. price (1 year lag)	.203128** (.067681)	.0613475 (.0461953)	-.0578125** (.0169387)	-.2746246** (.0573284)	-.0058933 (.0150478)	.0354873 (.0384144)
Interest rate (1 year lag)	.1459012 (.1493694)	-.1011872** (.04761)	.1516874** (.037383)	.1428036** (.059084)	.0716631** (.0332077)	.0221133 (.0395936)
Total Assets	-.0040528** (.0019611)	.0630428** (.0114923)	-.0010874** (.0004908)	.0301813** (.0142619)	-.0038975** (.000428)	.0773362** (.0094769)
Total exports	-.0190063** (.0055631)	.0833918** (.0090097)	-.0013365 (.0013923)	.0498709** (.011181)	.04396358* (.0010893)	.1143483** (.0072655)
Total R&D	.5030505** (.0294433)	.3827524** (.0192665)	.0871957** (.0073688)	.0104946 (.0239097)		
Experience	.5281621** (.1130916)	-.0663407** (.0134323)	.2066519** (.0283037)	.1095438** (.0166695)	.0467969* (.0251345)	-.0503672** (.0111419)
Foreign firm (dummy)	2.116113 (6.98521)	2.683946** (.3407266)	-4.197446** (1.748203)	-1.619184** (.4228421)	-1.22855 (2.407567)	-.7744257** (.2830958)
Number of obs.	4254	4253	4254	4253	4253	4253
Adj R-squared	0.8993	0.9124	0.5862	0.7640	0.5782	0.6091

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Appendix C

Figures for Chapter 1

Figure C.1: Transition path for the innovation rate

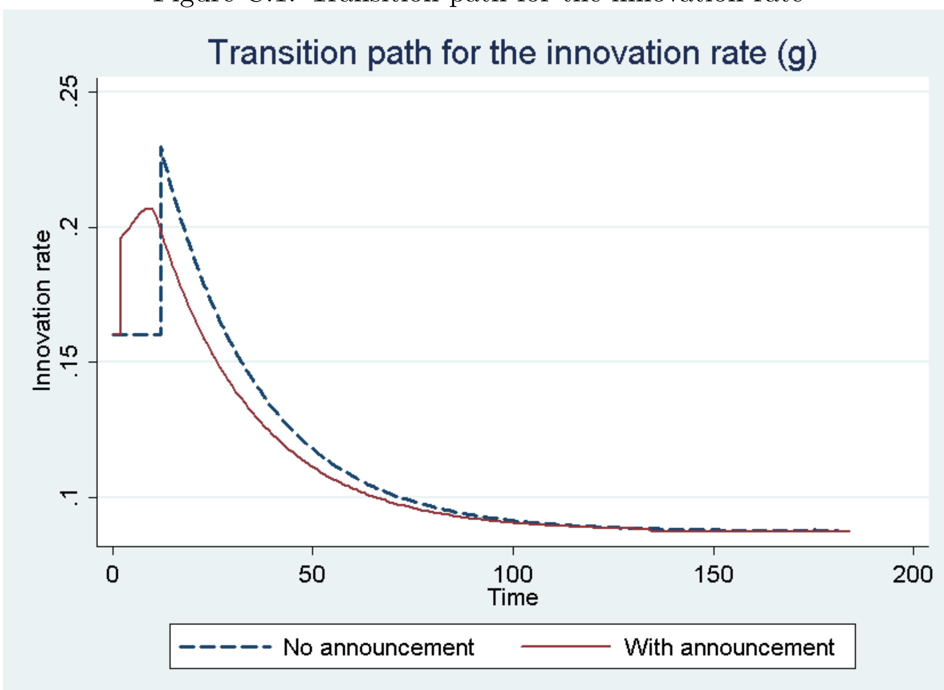


Figure C.2: Transition path for the imitation rate

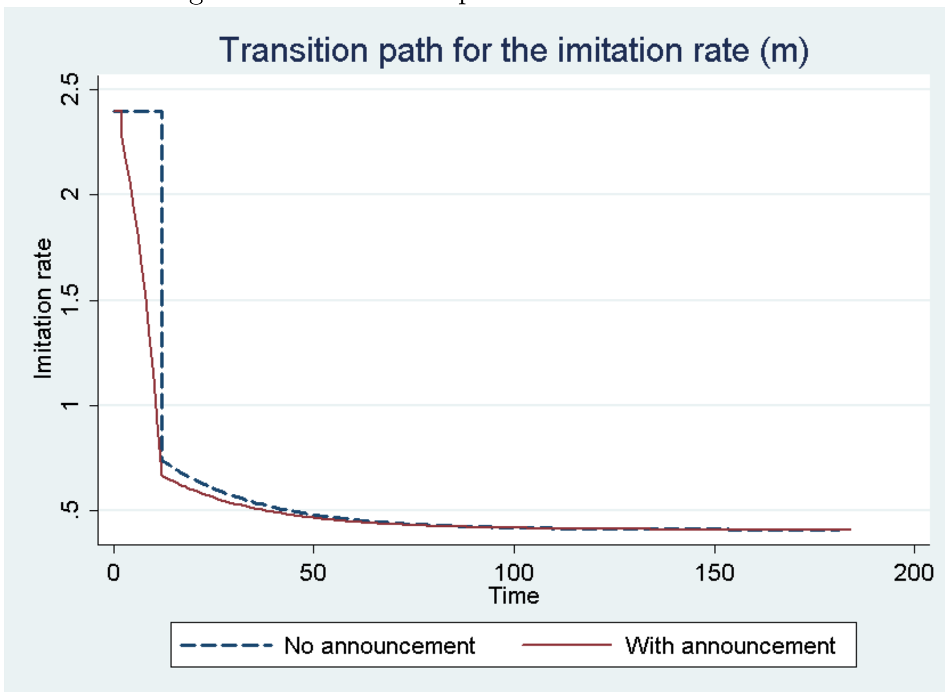


Figure C.3: Transition path for the fraction of goods that have not been imitated

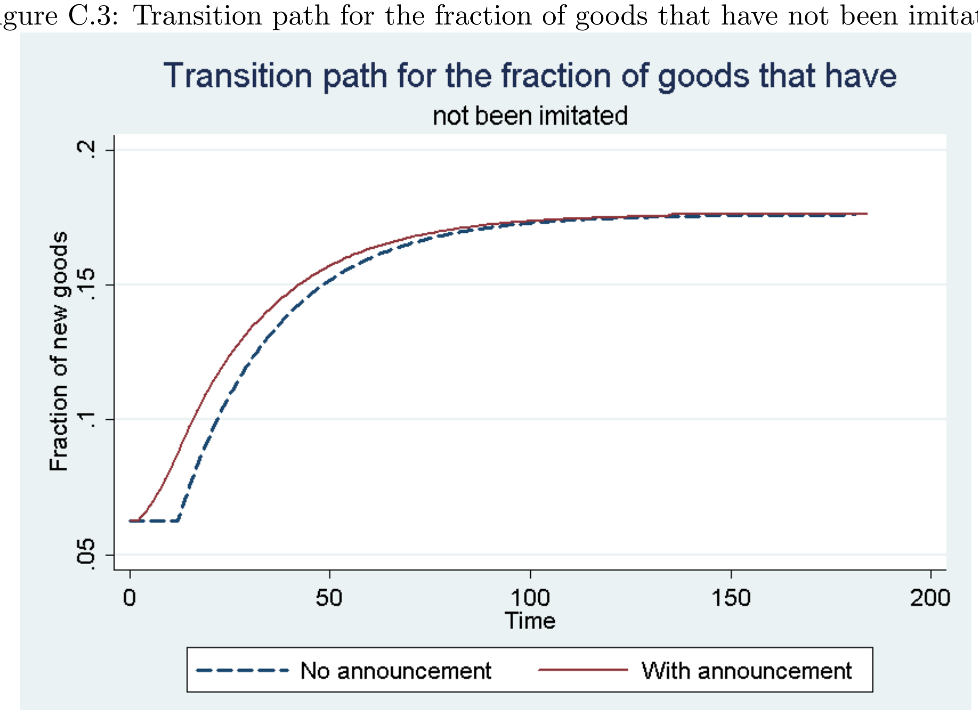


Figure C.4: The number of EU patent applications per year (for all the firms in the sample)

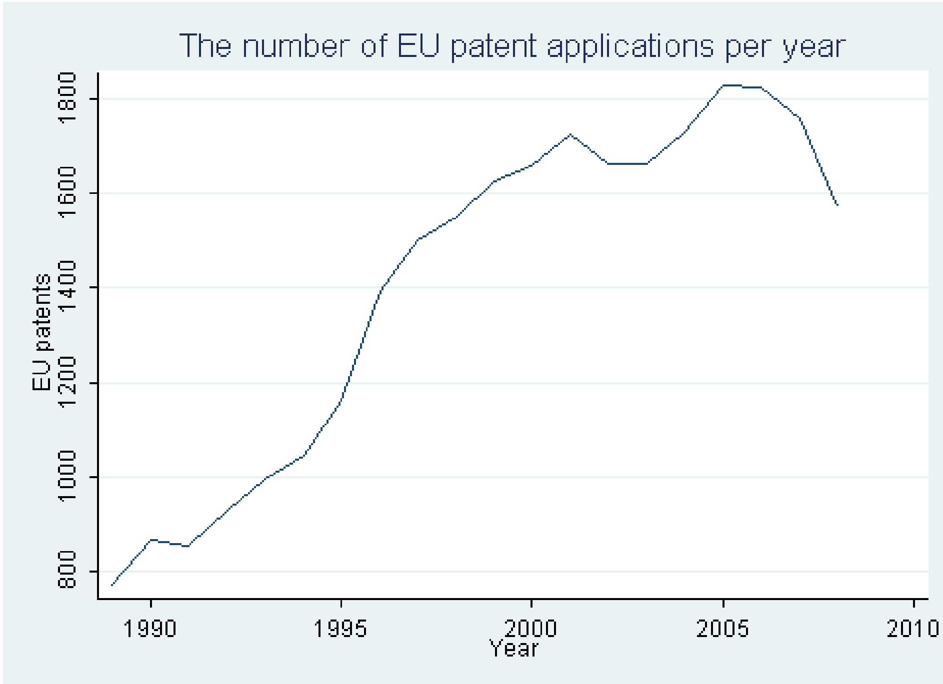


Figure C.5: The number of EU patent applications per year (domestic vs. foreign firms)

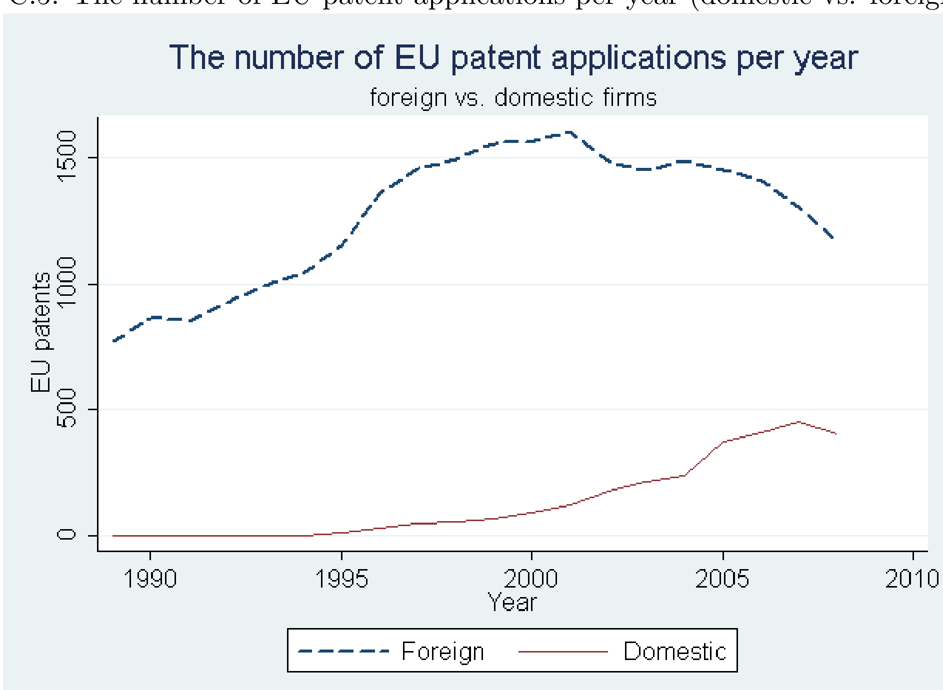


Figure C.6: The difference between the number of Indian and EU patent applications per year (where negative is set equal to zero)

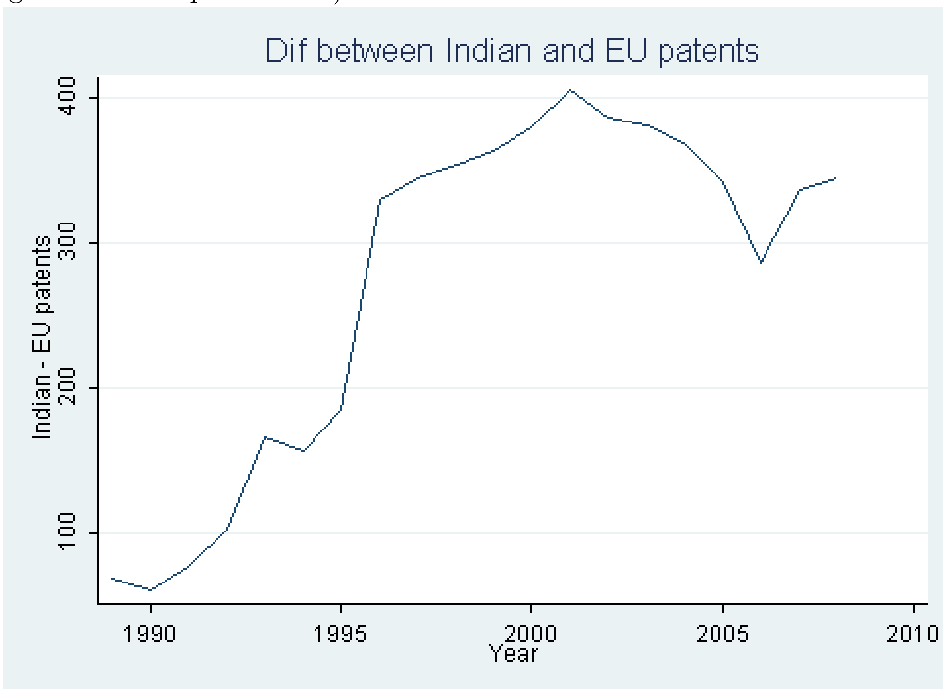


Figure C.7: The difference between the number of Indian and EU patent applications per year (domestic vs. foreign firms)

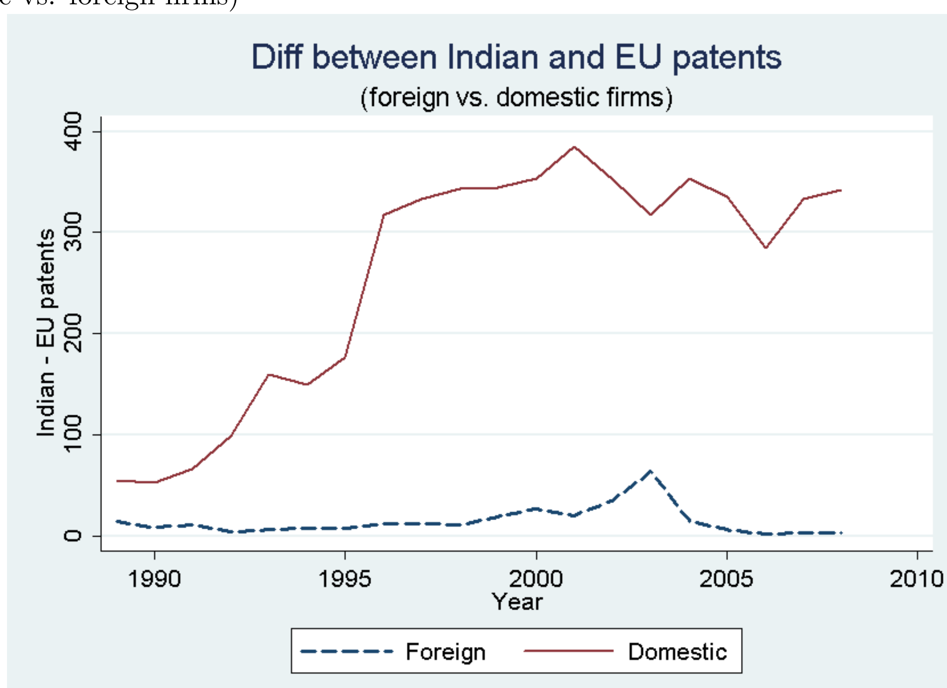


Figure C.8: Services Exported (full sample)

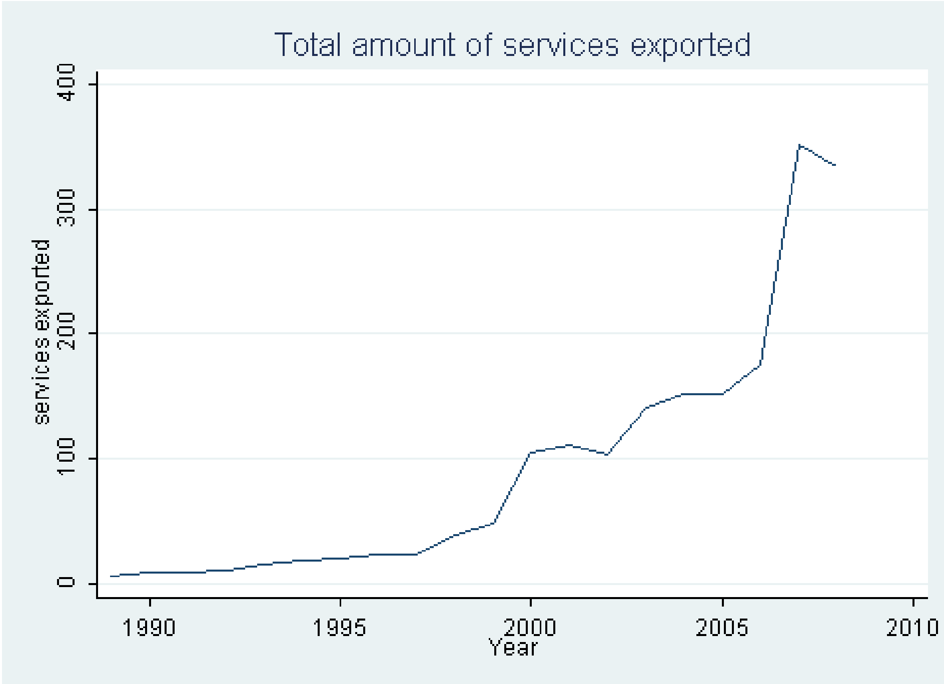


Figure C.9: Services Exported (domestic vs. foreign firms)

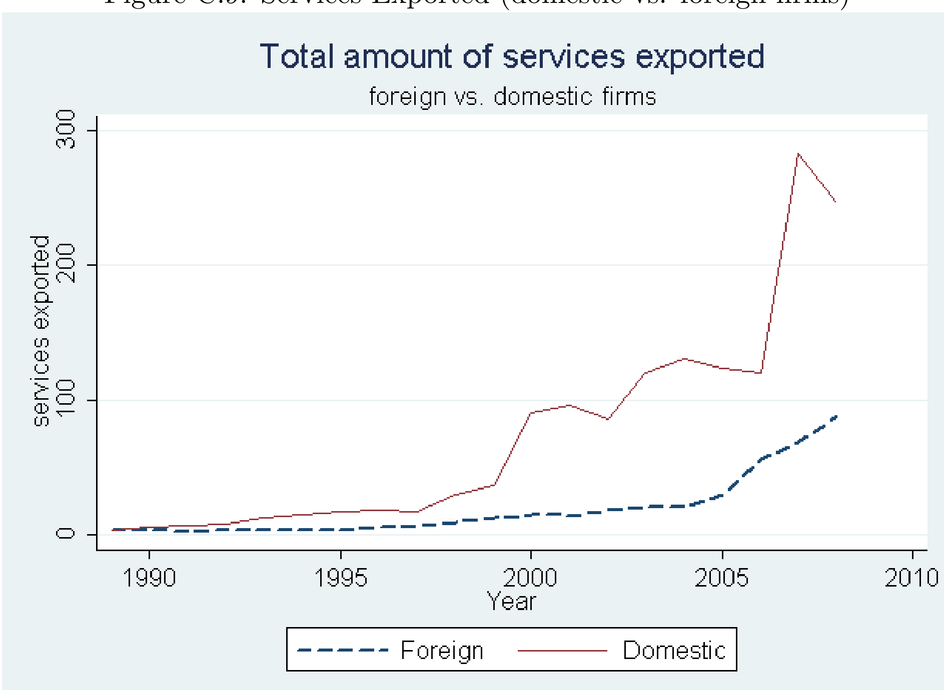


Figure C.10: Average ratio of EU to TOTAL number of patents (foreign firms)

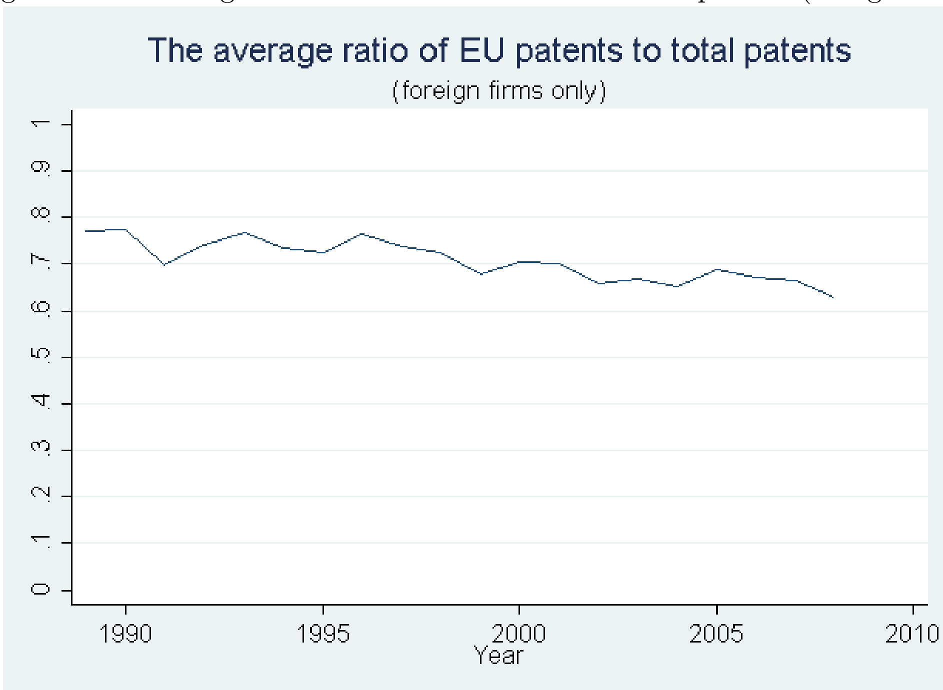


Figure C.11: Average ratio of EU to TOTAL number of patents (domestic firms)

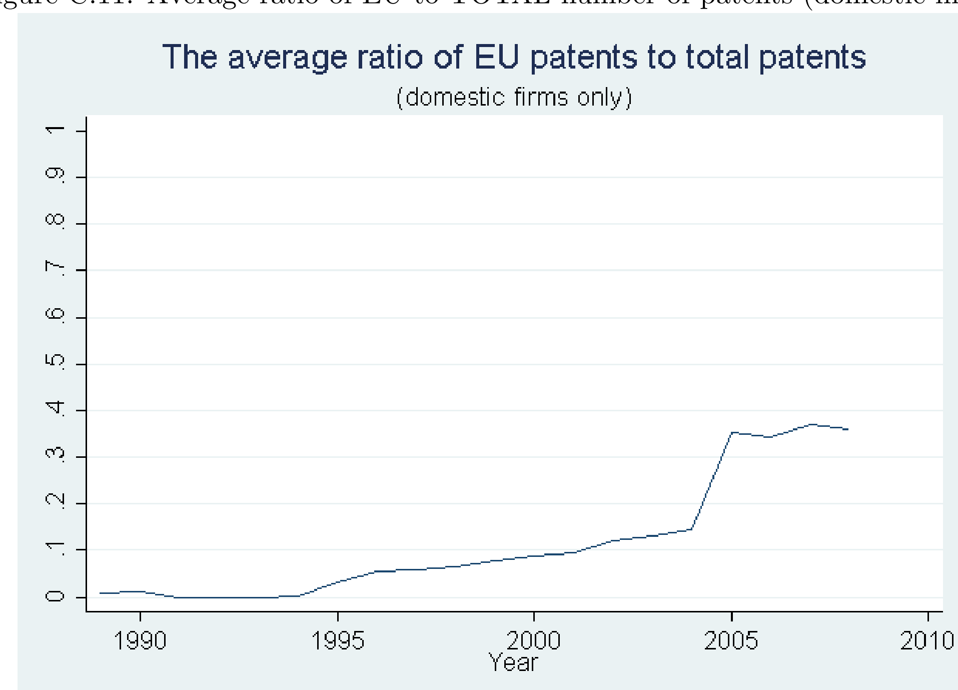


Figure C.12: Patent applications notified for opposition (pharma)

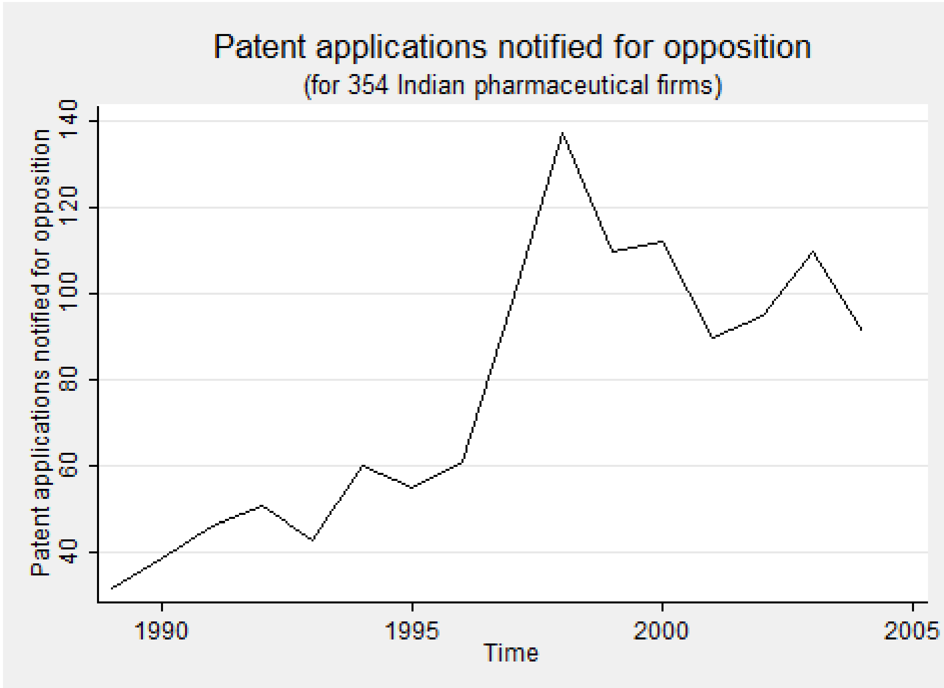
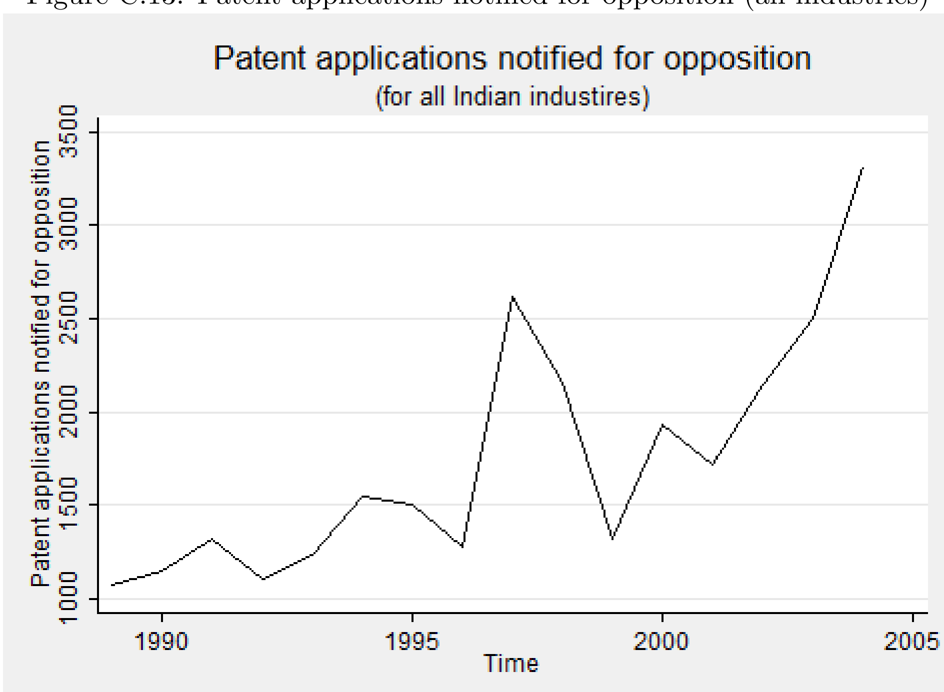


Figure C.13: Patent applications notified for opposition (all industries)



Appendix D

Appendix for Chapter 2 Section 2.3

These are the calculations that Helpman (1993) used to describe the effect of a decrease in m on innovation, and the fraction of goods that have not been imitated yet in the short run and long run. To do so, he first computes the negative eigenvalue and the corresponding eigenvector of the system.

$$\dot{\zeta} = g - (g+m)\zeta \tag{2.2}$$

$$\dot{g} = (L_{N} - \mathrm{a}g)\left[\rho + m + g - (1/\alpha - 1)(L_{N} - \mathrm{a}g)/\zeta\right] \tag{2.19}$$

The linearized system of (2.2)-(2.19) is:

$$\begin{bmatrix} \dot{\zeta} \\ \dot{g} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} \zeta - \bar{\zeta} \\ g - \bar{g} \end{bmatrix} \tag{D.1}$$

where

$$a_{11} = -(m+g)$$

$$a_{12} = m(m+g)$$

$$a_{21} = \frac{\alpha}{1-\alpha} \cdot (\rho + m + g)^2$$

$$a_{22} = (\rho + m + g)\left(\frac{\alpha}{1-\alpha} \cdot \frac{g}{g+m} + 1\right)$$

The solution is:

$$\zeta(t) = \bar{\zeta} + [\zeta(0) - \zeta]e^{-\lambda t}$$

$$g(t) = \bar{g} - [\zeta(0) - \zeta]\Lambda e^{-\lambda t}$$

where $-\lambda$ equals the negative characteristic root and $[1, -\Lambda]^T$ represents the characteristic vector associated with the negative characteristic root, with $\Lambda > 0$. By definition $A[1, -\Lambda]^T = -\lambda[1, -\Lambda]^T$, where A is the matrix on the right hand side of (D.1). Since the second row of the matrix is positive, we have $\Lambda > 0$. Helpman (1993) provides explicit formulas for λ and Λ. The characteristic equation associated with the matrix on the right hand side of (D.1) is:

$$x^2 - (a_{11} + a_{22})x + (a_{11}a_{22} - a_{12}a_{21}) = 0$$

Solving for the solution:

$$x_{1,2} = (a_{11} + a_{22}) \pm [(a_{11} - a_{22}) + 4a_{12}a_{21}]^{1/2}$$

Appendix E

Appendix for Chapter 2 Section 2.4

In this annex, I present the calculations behind the differential equations describing the equilibrium. Let $\zeta = \frac{n_N}{n}$.

$$\frac{\dot{\zeta}}{\zeta} = \frac{\dot{n}_N}{n_N} - \frac{\dot{n}}{n} = \frac{\dot{n} - \dot{n}_S}{n_N} - \frac{\dot{n}}{n} = \frac{g}{\zeta} - m - g$$
$$\dot{\zeta} = g - (m+g)\zeta \tag{2.30}$$

In the North:

$$E_N = p_N n_N x_N$$

Using (2.9), (2.11) and (2.16) we get:

$$\frac{\dot{E}_N}{E_N} = -\frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + g + \frac{\dot{v}_N}{v_N} \tag{E.1}$$

Using (2.9), (2.14) and (2.16) we get:

$$\frac{\pi_N}{v_N} = \frac{1-\alpha}{\alpha \mathrm{a}_N} \cdot \frac{L_N - \mathrm{a}_N g}{\zeta} \tag{E.2}$$

Re-write equation (E.1) using (8), (2.10) and (E.2):

$$\dot{g} = (L_N/\mathrm{a}_N - g)\left[\rho + m + g - \frac{(1/\alpha - 1)(L_N/\mathrm{a}_N - g)}{\zeta}\right] \tag{2.31}$$

In the South:

$$\frac{\dot{n}_S}{n_S} = m\frac{\zeta}{1-\zeta}$$

The resource constraint becomes:

$$n_S x_S = L_S - m(1+k)\frac{\zeta}{1-\zeta}$$

Since $p_S = \frac{w_S}{\alpha}$ and $v_S = \frac{w_S(1+k)}{\mathrm{a}_S} n_S$ we get:

$$\begin{aligned}
p_S &= \frac{v_S n_S}{\alpha(1+k)\mathrm{a}_S} \\
\dot{p}_S &= \frac{1}{\alpha(1+k)\mathrm{a}_S}(\dot{v}_S n_S + v_S \dot{n}_S \\
\frac{\dot{p}_S}{p_S} &= \frac{\dot{v}_S}{v_S} + \frac{\dot{n}_S}{n_S} = \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta}
\end{aligned}$$

Also

$$\begin{aligned}
&E_S = p_S n_S x_S = p_S \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right) \\
&\dot{E}_S = \dot{p}_S \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right) - p_S \dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} - \frac{p_S m(1+k)\mathrm{a}_S \dot{\zeta}}{(1-\zeta)^2} = \\
&= \dot{p}_S \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right) - p_S \dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} - \frac{p_S m(1+k)\mathrm{a}_S \left[g - (g+m)\zeta\right]}{(1-\zeta)^2}
\end{aligned}$$

We get

$$\begin{aligned}
\frac{\dot{E}_S}{E_S} &= \frac{\dot{p}_S}{p_S} - \frac{\dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S \left[g-(g+m)\zeta\right]}{(1-\zeta)^2 \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right)} \\
&= \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta} - \frac{\dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S \left[g-(g+m)\zeta\right]}{(1-\zeta)^2 \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right)}
\end{aligned}$$

But $\frac{\dot{E}_S}{E_S} = r - \rho$, which implies

$$r - \rho = \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta} - \frac{\dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S \left[g-(g+m)\zeta\right]}{(1-\zeta)^2 \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta} \right)} \tag{E.3}$$

(E.4)

$$\pi_S = \left(\frac{1}{\alpha} - 1\right) w_S x_S = \left(\frac{1}{\alpha} - 1\right) \frac{w_S x_S}{v_S} = \frac{1-\alpha}{\alpha} \frac{v_S n_S}{(1+k)\mathrm{a}_S} \frac{1}{n_S} \left(L_S - \frac{\zeta m(1+k)\mathrm{a}_S}{1-\zeta}\right)$$

Since $\frac{\pi_S}{v_S} + \frac{\dot{v}_S}{v_S} = r$ we get:

$$\frac{1-\alpha}{\alpha} \cdot \frac{1}{(1+k)\mathrm{a}_S} \cdot \left(L_S - m(k+1)\mathrm{a}_S \frac{\zeta}{1-\zeta}\right) + \frac{\dot{v}_S}{v_S} = r \tag{E.5}$$

From (2.25) and (E.5) we get:

$$\begin{aligned}
&\frac{1-\alpha}{\alpha} \cdot \frac{1}{(1+k)\mathrm{a}_S} \cdot \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}\right) + \frac{\dot{v}_S}{v_S} - \rho = \\
&= \frac{\dot{v}_S}{v_S} + m\frac{\zeta}{1-\zeta} - \frac{\dot{m}(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}}{L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}} - \frac{m(1+k)\mathrm{a}_S \left[g - (g+m)\zeta\right]}{(1-\zeta)^2 \left(L_S - m(1+k)\mathrm{a}_S \frac{\zeta}{1-\zeta}\right)}
\end{aligned}$$

$$\begin{aligned}
\dot{m} =& \frac{1-\zeta}{\zeta} \cdot \left[\rho + m \cdot \frac{\zeta}{1-\zeta} - \frac{1-\alpha}{\alpha} \cdot \frac{\left(L_S - \frac{\zeta m(1+k)\mathrm{a}_S}{1-\zeta}\right)}{(1+k)\mathrm{a}_S}\right] \cdot \frac{\left(L_S - \frac{\zeta m(1+k)\mathrm{a}_S}{1-\zeta}\right)}{(1+k)\mathrm{a}_S} \\
&- \frac{m}{\zeta(1-\zeta)} \left[g - (m+g)\zeta\right]
\end{aligned} \tag{2.32}$$

Appendix F

Appendix for Chapter 2 (the Quality ladder model with exogenous imitation)

This Appendixis based on the quality ladder model developed by Grossman and Helpman (1991a). The main features of the model are presented in the first part of the section, but the actual solving method will be different from the original paper in order to allow for analysis of transitional dynamics.

There are two countries, North and South. Each has a representative consumer (identical in both countries) and many firms. The Northern firms supply n_N goods, while the Southern firms supply n_S goods ($n_N + n_S = 1$).

Consumers

Consider an economy with a continuum of goods indexed by $j \in [0,1]$. Each good potentially can be improved an infinite number of times (indexed by qualities $\omega = 0, 1, 2, \ldots$). The increments to quality are common to all products and exogenously given by a parameter $\lambda > 1$. Each good may be supplied in all discovered quality levels.

Higher quality level of products gives more utility. A consumer has additively separable intertemporal preferences given by lifetime utility

$$U = \int_0^\infty e^{-\rho t} \log u(t) \, \mathrm{d}t \tag{F.1}$$

The instantaneous utility is given by the formula:

$$\log u(t) = \int_0^1 \log \left[\sum_\omega q_\omega(i) x_\omega(i,t) \right] \, \mathrm{d}i \tag{F.2}$$

where $x_\omega(i,t)$ is the consumption of quality level ω of product $i \in [0,1]$ at time t, and $q_\omega(i) = \lambda^\omega$ (at time $t = 0$, the lowest quality of each product is offered: $q_0(i) = 1$). Although the summation is over the set of qualities of product i that is available at time t, utility maximizing consumers will purchase only the product with the lowest price per unit of quality.

Every consumer maximizes discounted utility subject to an intertemporal budget constraint

$$\int_0^\infty e^{-R(t)} E(t)\,\mathrm{d}t = A(0) + \int_0^\infty e^{-R(t)} Y(t)\,\mathrm{d}t \tag{F.3}$$

where $R(t)$ is the cumulative interest factor up to time t, $R(t) = \int_0^t r(s)\,\mathrm{d}s$, and $A(0)$ is the value of initial asset holdings. Individuals hold assets in the form of ownership in firms, but with a diverse portfolio, any capital losses appear as capital gains elsewhere, so only the initial asset holdings remain. Aggregate labor income of all consumers is $Y(t) = L_N w_N(t) + L_S w_S(t)$, where $L_N w_N(t)$ is total labor income in the North at time t.

The expenditure flow for consumers at time t is given by

$$E(t) = \int_0^1 \left[\sum_\omega p_\omega(i,t) x_\omega(i,t) \right] \mathrm{d}i \tag{F.4}$$

where $p_\omega(i,t)$ is the price of a product i of quality ω at time t.

The consumer's utility maximization problem can be broken into three stages. In the first stage, he optimally allocates lifetime wealth across time. In the second stage, he optimally allocates expenditure at each point in time across products. In the last stage, he allocates expenditure at each instant for each product across available quality levels. Starting with the last stage, a consumer will allocate expenditure for each product to the quality level offering the lowest quality-adjusted price $p_\omega(i,t)/\lambda^\omega$. He will be indifferent between quality level ω and quality level $\omega - 1$ if the relative price equals the quality difference $p_\omega(i,t)/p_{\omega-1}(i,t) = \lambda$ (when indifferent he will go for the higher quality level). In the equilibrium only the highest quality will be sold.

In the second stage, consumers evenly spread expenditure across all products $E(i,t) = E(t)$ as the elasticity of substitution between any two products is constant at unity. The demand for each good is:

$$x(i,t) = \frac{E(t)}{p(i,t)} \tag{F.5}$$

where $E(t)$ represents total expenditure at time t and $p(i,t)$ is the lowest quality adjusted price.

In the first stage, consumers evenly spread lifetime expenditure across time, $E(t) = E$, as the utility function for each consumer is time separable and the aggregate prices do not vary across time. Consumers can borrow at a riskless rate of return (r) determined in equilibrium.

Consumers maximize their utility given the budget constraint. The solution is the standard differential equation:

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho \tag{F.6}$$

where r is the market interest rate and ρ is the common subjective discount rate.

At the steady state, $r(t) = \rho$, for all t.

Research and Development (R&D)

The model features endogenous and costly R&D. Consumers are willing to pay a premium for quality which provides an incentive for firms to perform R&D. The R&D success is modeled as a continuous Poisson process at each point in time, firms are paying a cost for a chance at winning a payoff. If a firms performs R&D at an intensity ι for an time interval $\mathrm{d}t$, this will require $a\iota \mathrm{d}t$ units of labor at a cost of $wa\iota \mathrm{d}t$ and leads to success with probability $\iota \mathrm{d}t$. The rate of innovation is denoted by g ($g \equiv \iota n_S$). The process of imitation is exogenous at rate m.

Consumers are also investors. They solve a portfolio allocation problem. They choose between shares in profit earning firms and interest bearing bonds with rate of return r. Shares in firms are risky assets but it is a idiosyncratic risk; there will be a sure return if they diversify the portfolio shares. In equilibrium, the consumers will be indifferent between different assets and interest bearing bonds.

The values of typical Northern firms are given by:

$$v_N(t) = \int_0^\infty \pi_N(t) e^{-R(t)} \,\mathrm{d}t \tag{F.7}$$

A Northern firm with product that has been copied by the South can expect a gain of $v_N \iota_N \mathrm{d}t$ at cost $W_N \mathrm{a}_N \iota_N \mathrm{d}t$ by undertaking R&D (innovation) at intensity ι_N, where v_N is the value of a typical Northern firm with domestic innovation, and π_N is the Northerns firm profit. This firm chooses its intensity of innovation ι_N to maximize its expected gain from R&D:

$$\max_{i_N \geq 0} (v_N(t) - \mathrm{a}_N w_N)\iota_N \tag{F.8}$$

where v_N is the reward to successful R&D for a typical Northern firm with domestic innovation and $w_N \mathrm{a}_N$ is the cost of R&D.

To generate finite rates of innovation, the expected reward for a successful R&D (innovation) should equal the expected R&D cost for each firm:

$$E(v_N) = w_N \mathrm{a}_N \tag{F.9}$$

Consumers diversify their portfolio such that the expected reward to successful is the average valuation.

From this point on I suppress the time subscripts for all variables.

Producers

Only Northern firms can innovate. Southern firms imitate at an exogenous rate m. A Northern firm can sell a newly designed good until a Southern firm imitates it. A Southern firm that successfully imitates a Northern good can sell the good until another innovation occurs.

All firms are choosing price p to maximize their profits $\pi = (p-c)x$, where c is the marginal cost and x is sales. Firms are charging monopoly prices (a markup over the marginal cost). Northern firm always win the price competition until an imitation succeeds.

A Northern firm charges a price λw_N, makes sales $x_N = E/(\lambda w_N)$ and has a marginal cost w_N. The instantaneous profits for these firms are:

$$\pi_N = \frac{(\lambda w_N - w_N)E}{\lambda w_N} = (1 - 1/\lambda)E \tag{F.10}$$

Equating the sums of the profit rates and the expected rates of capital gain/loss to the opportunity cost of funds in each region we derive the no arbitrage conditions (using equation F.6 and the comments that follow it).

A Northern firm with domestic R&D earns the reward:

$$\frac{\pi_N}{v_N} + \frac{\dot{v}_N}{v_N} - m = \rho \tag{F.11}$$

where π_N is instantaneous profits for the Northern firm with domestic R&D, v_N is its value, π_N/v_N is the dividend from holding shares in that firm, $\dot{v}_N/v_N$ is the rate of appreciation/depreciation of the shares, m is the rate of imitation and ρ is the subjective discount rate.

The resource market (market clearing conditions)

Northern firms allocate their resources between domestic innovation (R&D) and production of Northern goods, where L_N is the exogenous supply of labor in the North.

$$\mathrm{a}_N g + n_N x_N = L_N \tag{F.12}$$

Southern firms use their resources for the production of imitated goods (where L_S is the exogenous supply of labor in the South).

$$n_S x_S = L_S \tag{F.13}$$

Calculations

From (F.12) we can find: $x_N = (L_N - \mathrm{a}_N g)/n_N$. Northern firms are charging $p_N = \lambda w_N$, so $w_N = p_N/\lambda$. We can re-write the instantaneous profits:

$$\pi_N = (p_N - w_N)x_N = (p_N - p_N/\lambda)x_N = (1 - 1/\lambda)p_N(L_N - \mathrm{a}_N g)/n_N \tag{F.14}$$

From F.9, F.11, F.14 we get:

$$\frac{(\lambda-1)(L_N-\mathrm{a}_N g)}{n_N \mathrm{a}_N}+\frac{\dot{v}_N}{v_N}=r+m \tag{F.15}$$

Assume that there are no financial capital flows between the two regions, so that the North finances investment in R&D entirely with domestic savings. The lack of international capital mobility implies that the trade account is balanced at every point in time:

$$E_N=p_N n_N x_N=p_N n_N(L_N-\mathrm{a}_N g)/n_N=p_N(L_N-\mathrm{a}_N g)$$

$$\dot{E}_N=\dot{p}_N(L_N-\mathrm{a}_N g)-\mathrm{a}_N p_N \dot{g}$$

$$\frac{\dot{E}_N}{E_N}=\frac{\dot{p}_N(L_N-\mathrm{a}_N g)-\mathrm{a}_N p_N \dot{g}}{p_N(L_N-\mathrm{a}_N g)}=-\frac{\mathrm{a}_N \dot{g}}{(L_N-\mathrm{a}_N g)}+\frac{\dot{p}_N}{p_N} \tag{F.16}$$

From F.6, F.16 we get $-(\mathrm{a}_N\dot{g})/(L_N-\mathrm{a}_N g)+\dot{p}_N/p_N=r-\rho$, and therefore:

$$r=\rho-(\mathrm{a}_N\dot{g})/(L_N-\mathrm{a}_N g)+\dot{p}_N/p_N \tag{F.17}$$

We know that $p_N=\lambda w_N$, so $w_N=p_N/\lambda$ and $v_N=w_N\mathrm{a}_N$, and so $p_N=\lambda v_N/\mathrm{a}_N$ and $\dot{p}_N/p_N=\dot{v}_N/v_N$. Then (F.17) becomes:

$$r=\rho-\frac{(\mathrm{a}_N\dot{g})}{(L_N-\mathrm{a}_N g)}+\frac{\dot{v}_N}{v_N} \tag{F.18}$$

From F.15 and F.18 we get:

$$\frac{(\lambda-1)(L_N-\mathrm{a}_N g)}{n_N \mathrm{a}_N}+\frac{\dot{v}_N}{v_N}=\rho-\frac{(\mathrm{a}_N\dot{g})}{(L_N-\mathrm{a}_N g)}+\frac{\dot{v}_N}{v_N}+m$$

$$\dot{g}=\frac{(L_N-\mathrm{a}_N g)}{\mathrm{a}_N}\cdot\left[\rho+m-(\lambda-1)\frac{(L_N-\mathrm{a}_N g)}{n_N \mathrm{a}_N}\right] \tag{F.19}$$

We know that $n_N+n_S=1$

$$\dot{n}_N=g n_S-m n_N=g(1-n_N)-m n_N=g-(g+m)n_N \tag{F.20}$$

Equilibrium/ steady state:

The coordinates of the steady state $(\bar{n}_N, \bar{g})$ are solutions of the system:

$$\dot{n}_N = 0$$

$$\dot{g} = 0$$

The first equation, $\dot{n}_N = 0$, implies:

$$g - (g+m)n_N = 0$$

$$n_N = \frac{g}{g+m}$$

$$n_N = 1 - \frac{m}{g+m}$$

This means that n_N is a rational function of g , therefore the graph of n_N as a function of g is a hyperbola with the following asymptotes:

- horizontal asymptote $g = -m$ (which is outside our domain, since $-m$ is negative, and we consider only at $g > 0$
- vertical asymptote $n_N = 1$ (which is a natural limit for n_N since $n_N + n_S = 1$.

The second equation, $\dot{g} = 0$, implies:

$$\frac{(L_N - \mathrm{a}_N g)}{\mathrm{a}_N} \cdot \left[\rho + m - (\lambda - 1)\frac{(L_N - \mathrm{a}_N g)}{n_N \mathrm{a}_N}\right] = 0$$

Since $(L_N - \mathrm{a}_N g) > 0$, this gives

$$\rho + m = (\lambda - 1)\frac{(\frac{L_N}{\mathrm{a}_N} - g)}{n_N}$$

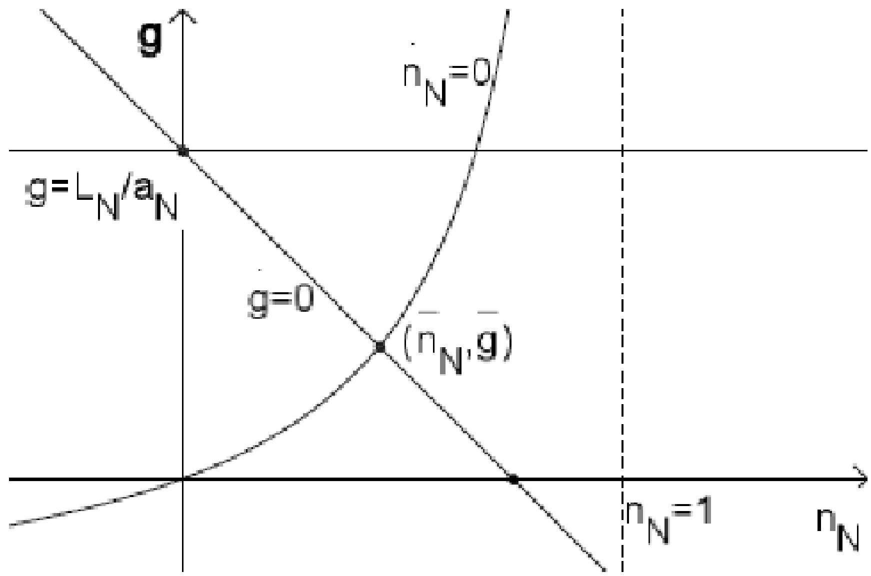
$$n_N = (\lambda - 1)\frac{(\frac{L_N}{\mathrm{a}_N} - g)}{\rho + m}$$

This means that n_N is a linear function of g , therefore the graph of n_N as a function of g is a straight line which crosses the axes as follows:

- intersects g-axis at $g = L_N/\mathrm{a}_N$ (which is outside our domain)

- intersects n_N-axis at $n_N = (\lambda - 1)(L_N/\mathrm{a}_N)/(\rho + m)$

Figure F.1: Phase diagram for long run equilibrium - Quality Ladder



The equations of the steady state are:

$$\bar{n}_N = \frac{\bar{g}}{\bar{g} + m} \tag{F.21}$$

$$\bar{n}_N = \frac{(\lambda - 1)(L_N/\mathrm{a}_N - \bar{g})}{(\rho + m)} \tag{F.22}$$

Solve for $\bar{g}$:

$$\frac{\bar{g}}{\bar{g} + m} = \frac{(\lambda - 1)(L_N/\mathrm{a}_N - \bar{g})}{(\rho + m)}$$

$$\bar{g} \cdot (\rho + m) = (\lambda - 1)(L_N/\mathrm{a}_N - \bar{g}) \cdot (\bar{g} + m)$$

This leads to a quadratic equation in $\bar{g}$:

$$\underbrace{(\lambda - 1)}_{A} \cdot \bar{g}^2 + \underbrace{[\rho + m + (\lambda - 1) \cdot (m - L_N/\mathrm{a}_N)]}_{B} \cdot \bar{g} + \underbrace{[-(\lambda - 1) \cdot m \cdot L_N/\mathrm{a}_N]}_{C} = 0$$

The discriminant is strictly positive:

$$\Delta = B^2 - 4 \cdot A \cdot C =$$
$$= \left[\rho + m + (\lambda - 1) \cdot \left(m - \frac{L_N}{\mathrm{a}_N}\right)\right]^2 - 4(\lambda - 1) \cdot \left[-(\lambda - 1) \cdot m \cdot \frac{L_N}{\mathrm{a}_N}\right] =$$
$$= \left[\rho + m + (\lambda - 1) \cdot \left(m - \frac{L_N}{\mathrm{a}_N}\right)\right]^2 + 4 \cdot (\lambda - 1)^2 \cdot m \cdot \frac{L_N}{\mathrm{a}_N} > 0$$

This gives two distinct solutions:

$$\bar{g}_1 = \frac{-B + \sqrt{\Delta}}{2A} \qquad \bar{g}_2 = \frac{-B - \sqrt{\Delta}}{2A}$$

Note that $\bar{g}_2 < 0$ (even if $B < 0$, since $4 \cdot A \cdot C > 0$ and so $|B| < \sqrt{\Delta}$): Hence this solution is irrelevant. We obtain only one relevant solution ($\bar{g}_1$), which from here onwards will be called $\bar{g}$:

$$\bar{g} = \bar{g}_1 = \frac{-B + \sqrt{\Delta}}{2A} = \frac{-\left[\rho + m + (\lambda - 1)(m - \frac{L_N}{\mathrm{a}_N})\right]}{2(\lambda - 1)} +$$
$$+ \frac{\sqrt{\left[\rho + m + (\lambda - 1)(m - \frac{L_N}{\mathrm{a}_N})\right]^2 + 4\frac{(\lambda-1)^2\, m\, L_N}{\mathrm{a}_N}}}{2(\lambda - 1)}$$

To quantify the effects of an increase in m on the coordinates of the steady state, we compute $\frac{\partial \bar{n}_N}{\partial m}$ and $\frac{\partial \bar{g}}{\partial m}$. We set

$$\frac{\partial \bar{g}}{\partial m} = \frac{\frac{\partial \sqrt{\Delta}}{\partial m} - \frac{\partial B}{\partial m}}{2(\lambda - 1)} = \frac{\frac{1}{2\sqrt{\Delta}}\frac{\partial \Delta}{\partial m} - \frac{\partial B}{\partial m}}{2(\lambda - 1)} = \frac{\frac{\partial \Delta}{\partial m} - 2 \cdot \sqrt{\Delta} \cdot \frac{\partial B}{\partial m}}{4(\lambda - 1)\sqrt{\Delta}}$$

Since A does not depend on m:

$$\frac{\partial \Delta}{\partial m} = \frac{\partial}{\partial m}\left(B^2 - 4 \cdot A \cdot C\right) = 2 \cdot B \cdot \frac{\partial B}{\partial m} - 4 \cdot A \cdot \frac{\partial C}{\partial m}$$

Since $\frac{\partial B}{\partial m} = 1 + (\lambda - 1) \cdot 1 = \lambda$, and $\frac{\partial C}{\partial m} = -(\lambda - 1) \cdot 1 \cdot L_N/\mathrm{a}_N$, we get

$$\frac{\partial \Delta}{\partial m} = 2B\lambda - 4A\left[-(\lambda - 1) \cdot L_N/\mathrm{a}_N\right] = 2B\lambda + 4(\lambda - 1)^2 L_N/\mathrm{a}_N$$

Therefore

$$\begin{aligned}\frac{\partial \bar{g}}{\partial m} &= \frac{\frac{\partial \Delta}{\partial m} - 2 \cdot \sqrt{\Delta} \cdot \frac{\partial B}{\partial m}}{4(\lambda - 1)\sqrt{\Delta}} = \frac{2B\lambda + 4(\lambda - 1)^2 L_N/\mathrm{a}_N - 2 \cdot \sqrt{\Delta} \cdot \lambda}{4(\lambda - 1)\sqrt{\Delta}} = \\ &= \frac{-2 \cdot (\sqrt{\Delta} - B) \cdot \lambda}{4(\lambda - 1)\sqrt{\Delta}} + \frac{4(\lambda - 1)^2 L_N/\mathrm{a}_N}{4(\lambda - 1)\sqrt{\Delta}} = \frac{-\lambda}{\sqrt{\Delta}} \cdot \frac{\sqrt{\Delta} - B}{2(\lambda - 1)} + \frac{(\lambda - 1)L_N/\mathrm{a}_N}{\sqrt{\Delta}} = \\ &= -\frac{\lambda}{\sqrt{\Delta}} \cdot \bar{g} + \frac{(\lambda - 1)L_N/\mathrm{a}_N}{\sqrt{\Delta}} = \frac{1}{\sqrt{\Delta}}\left[(\lambda - 1)L_N/\mathrm{a}_N - \lambda\bar{g}\right]\end{aligned}$$

We have obtained an expression for $\dfrac{\partial \bar{g}}{\partial m}$:

$$\frac{\partial \bar{g}}{\partial m} = \frac{1}{\sqrt{\Delta}}\left[(\lambda - 1)\frac{L_N}{\mathrm{a}_N} - \lambda\bar{g}\right] \tag{F.23}$$

Now compute $\dfrac{\partial \bar{n}_N}{\partial m}$ from (**??**):

$$\frac{\partial \bar{n}_N}{\partial m} = \frac{\frac{\partial \bar{g}}{\partial m} \cdot (\bar{g} + m) - \bar{g}\left(\frac{\partial \bar{g}}{\partial m} + 1\right)}{(\bar{g} + m)^2} = \frac{m \cdot \frac{\partial \bar{g}}{\partial m} - \bar{g}}{(\bar{g} + m)^2}$$

Use equation (F.23):

$$\begin{aligned}\frac{\partial \bar{n}_N}{\partial m} &= \frac{m \cdot \frac{1}{\sqrt{\Delta}}\left[(\lambda - 1)\frac{L_N}{\mathrm{a}_N} - \lambda\bar{g}\right] - \bar{g}}{(\bar{g} + m)^2} = \frac{m \cdot \left[(\lambda - 1)\frac{L_N}{\mathrm{a}_N} - \lambda\bar{g}\right] - \bar{g}\sqrt{\Delta}}{(\bar{g} + m)^2\sqrt{\Delta}} = \\ &= \frac{(\lambda - 1) \cdot m \cdot \frac{L_N}{\mathrm{a}_N} - (\lambda \cdot m + \sqrt{\Delta})\bar{g}}{(\bar{g} + m)^2\sqrt{\Delta}}\end{aligned}$$

We have obtained an expression for $\dfrac{\partial \bar{n}_N}{\partial m}$:

$$\frac{\partial \bar{n}_N}{\partial m} = \frac{(\lambda - 1) \cdot m \cdot \frac{L_N}{\mathrm{a}_N} - (\lambda \cdot m + \sqrt{\Delta})\bar{g}}{(\bar{g} + m)^2\sqrt{\Delta}} \tag{F.24}$$

In equation (F.23) use first equation (F.22), and then equation (F.21):

$$\frac{\partial \bar{g}}{\partial m} = \frac{1}{\sqrt{\Delta}}\left[(\lambda-1)\frac{L_N}{\mathrm{a}_N} - \lambda\bar{g}\right] = \frac{(\lambda-1)\left(\frac{L_N}{\mathrm{a}_N} - \bar{g}\right) - \bar{g}}{\sqrt{\Delta}} = \frac{\bar{n}_N(\rho+m) - \bar{g}}{\sqrt{\Delta}} =$$

$$= \frac{\frac{\bar{g}}{\bar{g}+m}\cdot(\rho+m) - \bar{g}}{\sqrt{\Delta}} = \frac{\bar{g}\cdot(\rho+m) - \bar{g}(\bar{g}+m)}{(\bar{g}+m)\sqrt{\Delta}} = \frac{\bar{g}\cdot(\rho-\bar{g})}{(\bar{g}+m)\sqrt{\Delta}} \quad \text{(F.25)}$$

If we write $m = \tilde{m} - \mu$ with $\tilde{m}$ constant, then a decrease in m is the same as an increase in μ. Since $\mu = \tilde{m} - m$, we see that:

$$\frac{\partial \bar{g}}{\partial \mu} = \frac{\partial \bar{g}}{\partial m}\cdot\frac{\partial m}{\partial \mu} = -\frac{\partial \bar{g}}{\partial m}$$

This means that when m decreases (μ increases) there will be an increase in $\bar{g}$ (the coordinate of the new steady state) if and only if $\bar{g} > \rho$. But we have an equation for $\bar{g}$:

$$\bar{g} = \bar{g}_1 = \frac{-B+\sqrt{\Delta}}{2A} = \frac{-\left[\rho + m + (\lambda-1)(m - \frac{L_N}{\mathrm{a}_N})\right]}{2(\lambda-1)} +$$

$$+ \frac{\sqrt{\left[\rho + m + (\lambda-1)(m - \frac{L_N}{\mathrm{a}_N})\right]^2 + 4\frac{(\lambda-1)^2\, m\, L_N}{\mathrm{a}_N}}}{2(\lambda-1)}$$

So given concrete numerical values for the parameters it is an easy computation to determine whether $\bar{g} > \rho$.

Now use this to find $\frac{\partial \bar{n}_N}{\partial m}$ from (F.21), by use of equation (F.25):

$$\frac{\partial \bar{n}_N}{\partial m} = \frac{\partial}{\partial m}\left(\frac{\bar{g}}{\bar{g}+m}\right) = \frac{\frac{\partial \bar{g}}{\partial m}\cdot(\bar{g}+m) - \bar{g}\left(\frac{\partial \bar{g}}{\partial m}+1\right)}{(\bar{g}+m)^2} = \frac{\frac{\partial \bar{g}}{\partial m}\cdot m - \bar{g}}{(\bar{g}+m)^2} =$$

$$= \frac{1}{(\bar{g}+m)^2}\cdot\left(\frac{\bar{g}\cdot(\rho-\bar{g})}{(\bar{g}+m)\sqrt{\Delta}}\cdot m - \bar{g}\right) = \frac{1}{(\bar{g}+m)^2}\cdot\left(\frac{\bar{n}_N\cdot(\rho-\bar{g})}{\sqrt{\Delta}}\cdot m - \bar{g}\right) =$$

$$= \frac{m\cdot\bar{n}_N\cdot(\rho-\bar{g}) - \sqrt{\Delta}\cdot\bar{g}}{\sqrt{\Delta}(\bar{g}+m)^2} = \frac{m\cdot\bar{n}_N\cdot(\rho-\bar{g}) - \sqrt{\Delta}\cdot\bar{n}_N(\bar{g}+m)}{\sqrt{\Delta}(\bar{g}+m)^2} =$$

$$= \frac{\bar{n}_N}{\sqrt{\Delta}(\bar{g}+m)}\left[\frac{m}{(\bar{g}+m)}\cdot(\rho-\bar{g}) - \sqrt{\Delta}\right] =$$

$$= \frac{\bar{n}_N}{\sqrt{\Delta}(\bar{g}+m)}\left[(1-\bar{n}_N)\cdot(\rho-\bar{g}) - \sqrt{\Delta}\right] \quad \text{(F.26)}$$

Linearization

$$\begin{cases} \dot{n}_N = g - (g+m) \cdot n_N & \text{(F.20)} \\ \dot{g} = (L_N/\mathrm{a}_N - g) \cdot [\rho + m - (\lambda - 1) \cdot (L_N/\mathrm{a}_N - g)/n_N] & \text{(F.19)} \end{cases}$$

We linearize the system (F.19)-(F.20) around the steady state $(\bar{n}_N, \bar{g})$:

$$\begin{pmatrix} \dot{n}_N \\ \dot{g} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \cdot \begin{pmatrix} n_N - \bar{n}_N \\ g - \bar{g} \end{pmatrix}$$

Calculate partial derivatives of the functions on right hand side and evaluate them at steady state:

$$a_{11} = \frac{\partial \dot{n}_N}{\partial n_N}(\bar{n}_N, \bar{g}) = -(\bar{g} + m)$$

$$a_{12} = \frac{\partial \dot{n}_N}{\partial g}(\bar{n}_N, \bar{g}) = 1 - \bar{n}_N = 1 - \frac{\bar{g}}{\bar{g}+m} = \frac{m}{\bar{g}+m}$$

$$a_{21} = \frac{\partial \dot{g}}{\partial n_N}(\bar{n}_N, \bar{g}) = \frac{(\lambda-1)\left(\frac{L_N}{\mathrm{a}_N} - \bar{g}\right)^2}{\bar{n}_N^2} = \frac{(\rho+m)^2(\lambda-1)\left(\frac{L_N}{\mathrm{a}_N} - \bar{g}\right)^2}{(\lambda-1)^2\left(L_N/\mathrm{a}_N - \bar{g}\right)^2} =$$

$$= \frac{(\rho+m)^2}{(\lambda-1)}$$

$$a_{22} = \frac{\partial \dot{g}}{\partial g}(\bar{n}_N, \bar{g}) = -1 \cdot \left[\rho + m - \frac{(\lambda-1)\left(\frac{L_N}{\mathrm{a}_N} - \bar{g}\right)}{\bar{n}_N}\right] + \frac{(\lambda-1)\left(\frac{L_N}{\mathrm{a}_N} - \bar{g}\right)}{\bar{n}_N} =$$

$$= -\left((\rho+m) - (\rho+m)\right) + (\rho+m) = (\rho+m)$$

The linearized system becomes:

$$\begin{pmatrix} \dot{n}_N \\ \dot{g} \end{pmatrix} = \begin{pmatrix} -(\bar{g}+m) & \frac{m}{\bar{g}+m} \\ \frac{(\rho+m)^2}{(\lambda-1)} & (\rho+m) \end{pmatrix} \cdot \begin{pmatrix} n_N - \bar{n}_N \\ g - \bar{g} \end{pmatrix}$$

We compute:

$$\mathrm{tr}(A) = a_{11} + a_{22} = -(\bar{g} + m) + (\rho + m) = \rho - \bar{g}$$

$$\begin{aligned}
\det(A) &= a_{11} \cdot a_{22} - a_{12} \cdot a_{21} = \\
&= -(\bar{g} + m) \cdot (\rho + m) - \frac{m}{\bar{g} + m} \cdot \frac{(\rho + m)^2}{(\lambda - 1)} = \\
&= -(\rho + m) \cdot \left[(\bar{g} + m) + \frac{m}{\bar{g} + m} \cdot \frac{\rho + m}{(\lambda - 1)} \right]
\end{aligned}$$

The determinant is negative, since each parenthesis is positive. However we simplify further the expression of the determinant in order to obtain a simpler expression for the eigenvalues of the matrix. Use the equations of the steady state (F.21) and (F.22):

$$\begin{aligned}
\det(A) &= -(\rho + m) \cdot \left[(\bar{g} + m) + m \cdot \frac{1}{\bar{g} + m} \cdot \frac{\rho + m}{(\lambda - 1)} \right] = \\
&= -(\rho + m) \cdot \left[(\bar{g} + m) + m \cdot \frac{\bar{n}_N}{\bar{g}} \cdot \frac{L_N/\mathrm{a}_N - \bar{g}}{\bar{n}_N} \right] = \\
&= -(\rho + m) \cdot \left[(\bar{g} + m) + m \cdot \frac{L_N/\mathrm{a}_N - \bar{g}}{\bar{g}} \right] = \\
&= -(\rho + m) \cdot \frac{\bar{g}^2 + m \cdot \bar{g} + m \cdot L_N/\mathrm{a}_N - m \cdot \bar{g}}{\bar{g}} = \\
&= -(\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}} < 0
\end{aligned}$$

The product of the two eigenvalues is $\det(A) < 0$. We conclude that the linearized system has two real eigenvalues, one positive and one negative. They are solutions of the characteristic equation:

$$\alpha^2 - \mathrm{tr}(A) \cdot \alpha + \det(A) = 0$$

$$\alpha^2 - (\rho - \bar{g}) \cdot \alpha - (\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}} = 0$$

$$\alpha^2 + (\bar{g} - \rho) \cdot \alpha - (\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}} = 0$$

The solutions of the characteristic equation are:

$$\begin{aligned}
\alpha_{1,2} &= \frac{\rho - \bar{g}}{2} \pm \frac{\sqrt{(\rho - \bar{g})^2 + 4 \cdot (\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}}}}{2} = \\
&= \frac{\rho - \bar{g}}{2} \pm \sqrt{\left(\frac{\rho - \bar{g}}{2} \right)^2 + \cdot (\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}}}
\end{aligned}$$

We can see which solution is positive:

$$\alpha_1 = \frac{\rho - \bar{g}}{2} + \sqrt{\left(\frac{\rho - \bar{g}}{2}\right)^2 + \cdot(\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}}} > 0$$

The other solution will have to be negative:

$$\alpha_2 = \frac{\rho - \bar{g}}{2} - \sqrt{\left(\frac{\rho - \bar{g}}{2}\right)^2 + \cdot(\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}}} < 0$$

General solution to the linearized system

$$\begin{pmatrix} \dot{n}_N \\ \dot{g} \end{pmatrix} = A \cdot \begin{pmatrix} n_N - \bar{n}_N \\ g - \bar{g} \end{pmatrix} \quad \text{with } A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

We write the negative eigenvalue of A as $\alpha_2 = -\alpha$ (with $\alpha > 0$).

$$\alpha = -\alpha_2 = -\frac{\rho - \bar{g}}{2} + \sqrt{\left(\frac{\rho - \bar{g}}{2}\right)^2 + \cdot(\rho + m) \cdot \frac{\bar{g}^2 + m \cdot L_N/\mathrm{a}_N}{\bar{g}}} > 0$$

Choose $\boldsymbol{\nu_1} = \begin{pmatrix} \nu_{11} \\ \nu_{12} \end{pmatrix}$ and $\boldsymbol{\nu_2} = \begin{pmatrix} \nu_{21} \\ \nu_{22} \end{pmatrix}$, non-zero eigenvectors for the eigenvalues α_1 and α_2 respectively: $A\boldsymbol{\nu_1} = \alpha_1\boldsymbol{\nu_1}$ and $A\boldsymbol{\nu_2} = \alpha_2\boldsymbol{\nu_2}$. For $\boldsymbol{\nu_2}$ this means:

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} \nu_{21} \\ \nu_{22} \end{pmatrix} = \alpha_2 \begin{pmatrix} \nu_{21} \\ \nu_{22} \end{pmatrix}$$

We see that $\begin{pmatrix} 0 \\ 1 \end{pmatrix}$ is not a solution (not an eigenvector for α_2), since:

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} a_{12} \\ a_{22} \end{pmatrix} \neq \begin{pmatrix} 0 \\ \alpha_2 \end{pmatrix} = \alpha_2 \begin{pmatrix} 0 \\ 1 \end{pmatrix} \quad \text{since } a_{12} \neq 0$$

Therefore we can choose the first component of $\boldsymbol{\nu_2}$ equal to 1: $\boldsymbol{\nu_2} = \begin{pmatrix} 1 \\ \nu_{22} \end{pmatrix}$. The second component of $\boldsymbol{\nu_2}$ is the solution of the system:

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} 1 \\ \nu_{22} \end{pmatrix} = \alpha_2 \begin{pmatrix} 1 \\ \nu_{22} \end{pmatrix}$$

Multiplying we get:

$$\begin{cases} a_{11} + \nu_{22} \cdot a_{12} = \alpha_2 \\ a_{21} + \nu_{22} \cdot a_{22} = \alpha_2 \cdot \nu_{22} \end{cases}$$

and the solution is $\nu_{22} = \dfrac{\alpha_2 - a_{11}}{a_{12}}$. Let Λ be defined such that $\boldsymbol{\nu_2} = \begin{pmatrix} 1 \\ \nu_{22} \end{pmatrix} = \begin{pmatrix} 1 \\ -\Lambda \end{pmatrix}$. Then, using the expressions for ν_{22} and α_2:

$$\begin{aligned} \Lambda = -\nu_{22} = -\frac{\alpha_2 - a_{11}}{a_{12}} = \frac{2a_{11} - 2\alpha_2}{2a_{12}} = \\ = \frac{2a_{11} - \left(a_{11} + a_{22} - \sqrt{(a_{11} + a_{22})^2 - 4(a_{11} \cdot a_{22} - a_{12} \cdot a_{21})}\right)}{2a_{12}} = \\ = \frac{a_{11} - a_{22}}{2a_{12}} + \frac{\sqrt{(a_{11} - a_{22})^2 - 4a_{12} \cdot a_{21}}}{2a_{12}} = \\ = \frac{-(\bar{g} + \rho + 2m) + \sqrt{(\bar{g} + \rho + 2m)^2 + 4 \cdot m \cdot \frac{(\rho + m)(L_N/\mathrm{a}_N - \bar{g})}{\bar{g}}}}{2\frac{m}{\bar{g}+m}} > 0 \end{aligned}$$

The general solution of the linearized system

$$\begin{pmatrix} \dot{n}_N \\ \dot{g} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \cdot \begin{pmatrix} n_N - \bar{n}_N \\ g - \bar{g} \end{pmatrix}$$

is given by:

$$\begin{pmatrix} n_N(t) \\ g(t) \end{pmatrix} = \begin{pmatrix} \bar{n}_N \\ \bar{g} \end{pmatrix} + \begin{pmatrix} \nu_{11} & \nu_{21} \\ \nu_{12} & \nu_{22} \end{pmatrix} \cdot \begin{pmatrix} C_1 \cdot e^{\alpha_1 t} \\ C_2 \cdot e^{\alpha_2 t} \end{pmatrix}$$

Since the eigenvalue α_1 is positive, it corresponds to an unstable path. We choose, therefore, $C_1 = 0$ and get:

$$\begin{cases} n_N(t) = \bar{n}_N + C_2 \cdot e^{-\alpha t} \\ g(t) = \bar{g} + C_2 \cdot (-\Lambda) \cdot e^{-\alpha t} \end{cases}$$

We set $C_2 = n_N(0) - \bar{n}_N$ to satisfy the initial condition for $n_N(t)$ (which is $n_N(0) = \bar{n}_N$), and get the solution for the linearized system:

$$\begin{cases} n_N(t) = \bar{n}_N + (n_N(0) - \bar{n}_N) \cdot e^{-\alpha t} \\ g(t) = \bar{g} + (n_N(0) - \bar{n}_N) \cdot (-\Lambda) \cdot e^{-\alpha t} \end{cases}$$

Taking into account the initial condition $n_N(0) = \bar{n}_N$ we compute the partial derivaties with respect to m:

$$\begin{aligned} \frac{\partial n_N(t)}{\partial m} &= \frac{\partial \bar{n}_N}{\partial m} + \frac{\partial}{\partial m}(n_N(0) - \bar{n}_N) \cdot e^{-\alpha t} + (n_N(0) - \bar{n}_N) \cdot \frac{\partial}{\partial m}(e^{-\alpha t}) = \\ &= \frac{\partial \bar{n}_N}{\partial m} - \frac{\partial \bar{n}_N}{\partial m} \cdot e^{-\alpha t} + 0 = \frac{\partial \bar{n}_N}{\partial m} \cdot (1 - e^{-\alpha t}) \end{aligned}$$

$$\begin{aligned} \frac{\partial g(t)}{\partial m} &= \frac{\partial \bar{g}}{\partial m} - \frac{\partial}{\partial m}(n_N(0) - \bar{n}_N) \cdot \Lambda \cdot e^{-\alpha t} - (n_N(0) - \bar{n}_N) \cdot \frac{\partial}{\partial m}(\Lambda \cdot e^{-\alpha t}) = \\ &= \frac{\partial \bar{g}}{\partial m} + \frac{\partial \bar{n}_N}{\partial m} \cdot \Lambda \cdot e^{-\alpha t} + 0 = \frac{\partial \bar{g}}{\partial m} + \frac{\partial \bar{n}_N}{\partial m} \cdot \Lambda \cdot e^{-\alpha t} \end{aligned}$$

This gives by using equations (F.25) and (F.26):

$$\begin{aligned} \frac{\partial g(0)}{\partial \mu} &= -\frac{\partial g(0)}{\partial m} = -\left(\frac{\partial \bar{g}}{\partial m} + \frac{\partial \bar{n}_N}{\partial m} \cdot \Lambda \cdot e^{-\alpha 0} \right) = \\ &= -\left(\frac{\bar{g} \cdot (\rho - \bar{g})}{(\bar{g} + m)\sqrt{\Delta}} + \frac{\bar{n}_N}{\sqrt{\Delta}(\bar{g} + m)} \left[(1 - \bar{n}_N) \cdot (\rho - \bar{g}) - \sqrt{\Delta} \right] \cdot \Lambda \cdot 1 \right) = \\ &= -\frac{(\rho - \bar{g})}{(\bar{g} + m)\sqrt{\Delta}} \cdot \left(\bar{g} + \Lambda \cdot \bar{n}_N \cdot (1 - \bar{n}_N) - \Lambda \cdot \frac{\sqrt{\Delta}}{\rho - \bar{g}} \cdot \bar{n}_N \right) = \\ &= \frac{(\bar{g} - \rho)}{(\bar{g} + m)\sqrt{\Delta}} \cdot \left(\bar{g} + \Lambda \cdot \bar{n}_N \cdot (1 - \bar{n}_N) + \Lambda \cdot \frac{\sqrt{\Delta} \cdot \bar{n}_N}{\bar{g} - \rho} \right) \end{aligned}$$

We determine the sign of $\frac{\partial g(0)}{\partial \mu}$:

$$\frac{\partial g(0)}{\partial \mu} = \underbrace{\frac{(\bar{g}-\rho)}{(\bar{g}+m)\sqrt{\Delta}}}_{>0} \cdot \left(\underbrace{\bar{g} + \Lambda \cdot \bar{n}_N \cdot (1-\bar{n}_N)}_{>0} + \underbrace{\Lambda \cdot \frac{\sqrt{\Delta} \cdot \bar{n}_N}{\bar{g}-\rho}}_{>0} \right)$$

However note that the sign of the second factor is not completely determined by the sign of $(\bar{g}-\rho)$ (it can be positive also when $(\bar{g}-\rho) < 0$), as was the case for $\frac{\partial \bar{g}}{\partial \mu}$. But we can say that $\frac{\partial g(0)}{\partial \mu}$ and $\frac{\partial \bar{g}}{\partial \mu}$ are both positive when $(\bar{g}-\rho) > 0$.

Equilibrium conditions:

The two differential equations that describe the equilibrium are (F.27) and (F.28). In these equations g is a jump variable while n_N is a state variable.

$$\dot{n}_N = g - (g+m) \cdot n_N \tag{F.27}$$

$$\dot{g} = (L_N/\mathrm{a}_N - g) \cdot \left(\rho + m - \frac{(\lambda-1)(L_N/\mathrm{a}_N - g)}{n_N} \right) \tag{F.28}$$

Calculations deriving the above mentioned differential equations along with derivations of the linearized system (and comparative statics with respect to μ, where $m = \tilde{m} - \mu$) are presented above.

Figure F.2: Phase diagram for short run changes - Quality Ladder

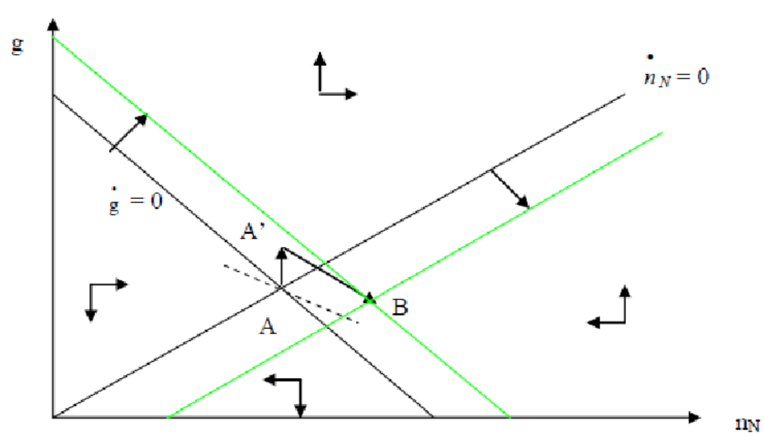


Figure F.2 represents the phase diagram for the system describe by equations (F.27) and (F.28). The thick curves represent the equation $\dot{g} = 0$ and the thin curves represent the equation $\dot{n}_N = 0$. The intersection of these two curves at point A describes the steady-state long-run equilibrium. The equilibrium trajectory consists of the saddle path that converges to A. Along this saddle path the rate of innovation decreases and the amount of Northern products increases over time whenever innovation is above the steady-state value. The opposite is true when innovation is below the steady-state value. A reduction in the rate of imitation (an increase in μ) shifts both curves $\dot{g} = 0$ and $\dot{n}_N = 0$ to the right, with the latter shifting by proportionately more. The result is that the long-run equilibrium point shifts down and to the right (B), implying that the long-run rate of innovation g declines and the long-run amount of Northern products increases. But if the rate of innovation was to rise temporarily, both regions might gain, even though temporarily. In the short run, the amount of products manufactured in the North does not change while the innovation rate increases ($\frac{\partial g(0)}{\partial \mu}$ is positive when $(\bar{g} - \rho) > 0$). This is represented in the graph above as a shift from A to A'. Therefore initially the system jumps from A to A' and subsequently follows the saddle path to B. The rate of innovation remains higher at all points in time until it reaches its steady-state value.

The following numerical example will show the transitional dynamics following the imposition of stronger IPR. Set the unit labor requirement in innovation to $\mathrm{a}_N = 5$, and the discount rate to $r = 0.2$, Northern labor supply $L_N = 10$, the initial imitation intensity $m = 0.6$ (which will decrease to 0.5 when stronger IPR are imposed).

The rate of innovation rises temporarily as a result of tighter IPRs. Therefore initially the system jumps from A to A' and subsequently follows the saddle path to B. The new steady-state value for the innovation rate is below the initial steady-state value.

Figure F.3: Transition path for the innovation rate when imitation is exogenous - Quality ladder

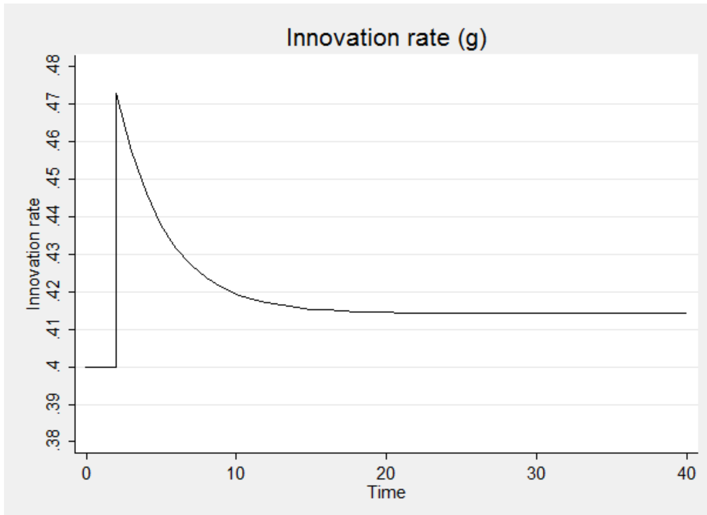
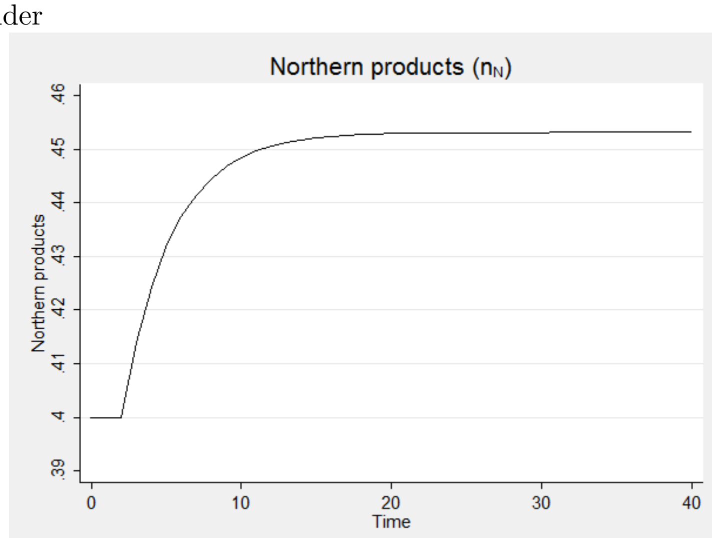


Figure F.4: Transition path for the fraction of products not imitated when imitation is exogenous - Quality ladder



Appendix G

Appendix for Chapter 2 (the Quality ladder model with endogenous imitation)

This section is based on the quality ladder model developed by Grossman and Helpman (1991a). The main features of the model are presented in the first part of the section, but the actual solving method will be different from the original paper in order to allow for transitional dynamics analysis.

There are two countries, North and South. Each has a representative consumer (identical in both countries) and many firms. The Northern firms supply n_N goods, while the Southern firms supply n_S goods ($n_N + n_S = 1$).

Consumers

This part is identical with the situation presented in F (page 120).

Research and Development (R&D)

The model features endogenous and costly R&D. Consumers are willing to pay a premium for quality which provides an incentive for firms to perform R&D. The process of innovation and imitation are similar, but they have different resource requirements: a_N is the resource requirement for a Northern firm performing R&D in the North, and $(1+k)\mathrm{a}_S$ for imitation targeting a Northern product. In this model changes into the strength of Southern IPR protection are reflected into changes in the parameter k. Higher levels of k are consistent with stronger IPR (reduces imitation efficiency). The corresponding R&D intensities are: ι_N and ι_S. The rate of innovation is denoted by g ($g \equiv \iota_N n_S$) and the rate of imitation is denoted by m ($m \equiv \iota_S n_N$).

The value of typical Southern firm is given by:

$$v_S(t) = \int_0^\infty \pi_S(t) e^{-R(t)} \, \mathrm{d}t \tag{G.1}$$

To generate finite rates of innovation, the expected reward for a successful R&D (innovation or imitation) should equal the expected R&D cost for each firm:

$$E(v_S) = (1+k)\mathrm{a}_S w_S \tag{G.2}$$

Corresponding valuation for the Northern firms (F.7) and the free-entry condition for Northern R&D (9′) are given in F (page 123).

Producers

Only Northern firms can innovate. Southern firms imitate. A Northern firm can sell a newly designed good until a Southern firm imitates it. A Southern firm can sell an imitated product until another innovation occurs.

Southern firms are charging $p_S = \varepsilon w_S$, so $w_S = p_S/\varepsilon$, where $\varepsilon > 1$.

Instantaneous profits:

$$\pi_S = (p_S - w_S)x_S = \left(p_S - \frac{p_S}{\varepsilon}\right) x_S \tag{G.3}$$

A Southern firm targeting a Northern firm earns the reward:

$$\frac{\pi_S}{v_S} + \frac{\dot{v}_S}{v_S} - g = \rho \tag{G.4}$$

where π_S is instantaneous profits for the Northern firm with domestic R&D, v_S is its value, π_S/v_S is the dividend from holding shares in that firm, $\dot{v}_s/v_S$ is the rate of appreciation/depreciation of the shares, g is the rate of innovation and ρ is the subjective discount rate.

Profits (F.10) and no-arbitrage condition (F.11) for the Northern firms are presented in Appendix F (pages 124 and 124).

The resource market (market clearing conditions)

Southern firms use their resources for imitation (R&D) and the production of imitated goods (where L_S is the exogenous supply of labor in the South).

$$(1+k)\mathrm{a}_S m + n_S x_S = L_S \tag{G.5}$$

The market clearing condition (F.12)for the North is presented in Appendix F (page 124).

Calculations

From (F.12) we find:

$$x_N = (L_N - \mathrm{a}_N g)/n_N \tag{G.6}$$

From (G.5) we find:

$$x_S = (L_S - \mathrm{a}_S m)/n_S \tag{G.7}$$

In the North

From (F.9), (F.11), (G.6) we get

$$\frac{(\lambda-1)(L_N - \mathrm{a}_N g)}{(n_N \mathrm{a}_N)} + \frac{\dot{v}_N}{v_N} = r + m \tag{G.8}$$

$$E_N = p_N n_N x_N = p_N n_N \frac{L_N - \mathrm{a}_N g}{n_N} = p_N(L_N - \mathrm{a}_N g)$$

$$\dot{E}_N = \dot{p}_N(L_N - \mathrm{a}_N g) - \mathrm{a}_N p_N \dot{g}$$

$$\frac{\dot{E}_N}{E_N} = \frac{\dot{p}_N(L_N - \mathrm{a}_N g) - \mathrm{a}_N p_N \dot{g}}{p_N(L_N - \mathrm{a}_N g)} = -\frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + \frac{\dot{p}_N}{p_N}$$

But $\frac{\dot{E}_N}{E_N} = r - \rho$, and using the above equation we get:

$$-\frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + \frac{\dot{p}_N}{p_N} = r - \rho \tag{G.9}$$

$$r = \rho - \frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + \frac{\dot{p}_N}{p_N} \tag{G.10}$$

We know that $p_N = \lambda w_N$ and $v_N = w_N \mathrm{a}_N$, therefore

$$p_N = \lambda v_N$$
$$\frac{\dot{p}_N}{p_N} = \frac{\dot{v}_N}{v_N}$$

Then (G.10) becomes:

$$r = \rho - \frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + \frac{\dot{v}_N}{v_N} \tag{G.11}$$

From (G.8) and (G.11) we get:

$$\frac{(\lambda - 1)(L_N - \mathrm{a}_N g)}{n_N \mathrm{a}_N} + \frac{\dot{v}_N}{v_N} = \rho - \frac{\mathrm{a}_N \dot{g}}{L_N - \mathrm{a}_N g} + \frac{\dot{v}_N}{v_N} + m \tag{G.12}$$
$$\dot{g} = \frac{L_N - \mathrm{a}_N g}{\mathrm{a}_N} \cdot \left[\rho + m - \frac{(\lambda - 1)(L_N - \mathrm{a}_N g)}{n_N \mathrm{a}_N} \right] \tag{G.13}$$

Equation of motion for the northern products:

We know that $n_N + n_S = 1$.

$$\dot{n}_N = g n_S - m n_N = g(1 - n_N) - m n_N = g - (g + m) n_N \tag{G.14}$$

In the South

From (G.2), ((G.4), (G.7) we get

$$\frac{(\varepsilon - 1)(L_S - \mathrm{a}_S m)}{n_S (1 + k) \mathrm{a}_S} + \frac{\dot{v}_S}{v_S} = r + g \tag{G.15}$$
$$E_S = p_S n_S x_S = p_S n_S \frac{L_S - \mathrm{a}_S m}{n_S} = p_S (L_S - \mathrm{a}_S m) \tag{G.16}$$
$$\dot{E}_S = \dot{p}_S (L_S - \mathrm{a}_S m) - \mathrm{a}_S p_S \dot{m} \tag{G.17}$$
$$\frac{\dot{E}_S}{E_S} = \frac{\dot{p}_S (L_S - \mathrm{a}_S m) - \mathrm{a}_S p_S \dot{m}}{p_S (L_S - \mathrm{a}_S m)} = -\frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{p}_S}{p_S} \tag{G.18}$$

But $\frac{\dot{E}_S}{E_S} = r - \rho$. Using the above equation we get

$$-\frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{p}_S}{p_S} = r - \rho \tag{G.19}$$

$$r = \rho - \frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{p}_S}{p_S} \tag{G.20}$$

$$\tag{G.21}$$

We know that $p_S = \varepsilon w_S$ and $v_S = (1+k) w_S \mathrm{a}_S$ we get

$$p_S = \frac{\varepsilon v_S}{\mathrm{a}_S}$$

$$\frac{\dot{p}_S}{p_S} = \frac{\dot{v}_S}{v_S}$$

Then (G.20), becomes:

$$-\frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{p}_S}{p_S} = r - \rho \tag{G.22}$$

$$r = \rho - \frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{v}_S}{v_S} \tag{G.23}$$

$$\tag{G.24}$$

From (G.15) and (G.23) we get:

$$\frac{(\varepsilon - 1)(L_S - \mathrm{a}_S m)}{n_S (1+k) \mathrm{a}_S} + \frac{\dot{v}_S}{v_S} = \rho - \frac{\mathrm{a}_S \dot{m}}{L_S - \mathrm{a}_S m} + \frac{\dot{v}_S}{v_S} + g \tag{G.25}$$

$$\dot{m} = \frac{L_S - \mathrm{a}_S m}{\mathrm{a}_S} \cdot \left[\rho + g - \frac{(\varepsilon - 1) \cdot (L_S - \mathrm{a}_S m)}{(1 - n_N)(1+k) \mathrm{a}_S} \right] \tag{G.26}$$

Equilibrium conditions

The three differential equations that describe the equilibrium are (G.13), (G.14) and (G.26). In these equations g and m are jump variable while n_N is a state variable:

$$\dot{g} = \frac{L_N - \mathrm{a}_N g}{\mathrm{a}_N} \cdot \left[\rho + m - (\lambda - 1) \frac{L_N - \mathrm{a}_N g}{n_N \mathrm{a}_N} \right] \tag{G.13}$$

$$\dot{n}_N = g - (g + m) n_N \tag{G.14}$$

$$\dot{m} = \frac{L_S - a_S m}{a_S} \cdot \left[\rho + g - (\varepsilon - 1) \frac{L_S - a_S m}{(1 - n_N)(1 + k) a_S} \right] \tag{G.26}$$

The following numerical example will show the transitional dynamics following the imposition of stronger IPR. Set the unit labor requirement in innovation to $a_N = 10$ and imitation $a_S = 5$, and the discount rate to $\rho = .8$. Lambda is 1.2 and epsilon is 1.2. Northern labor supply $L_N = 10$, Southern labor supply $L_S = 20$ the initial IPR parameter $k = 0$ (which will increase to 0.1 when stronger IPR are imposed such that the labor requirement coefficient $(1 + k)a_S$ increases with stronger IPR). The rate of innovation rise temporarily as a result of tighter IPRs, but then it decreases below the initial steady-state. Imitation falls abruptly and than it stars increasing slowly reaching a new steady state below the initial one. The amount of products produce in the North grows smoothly.

Figure G.1: Transition path for the innovation rate when imitation is endogenous - Quality ladder

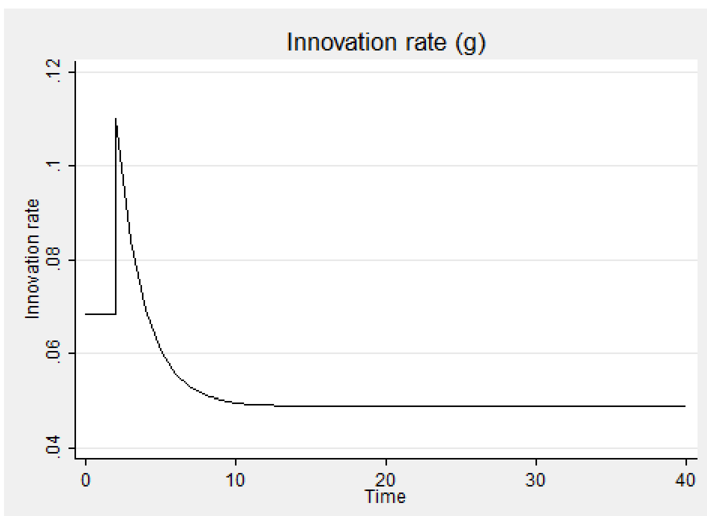


Figure G.2: Transition path for the imitation rate when imitation is endogenous - Quality ladder

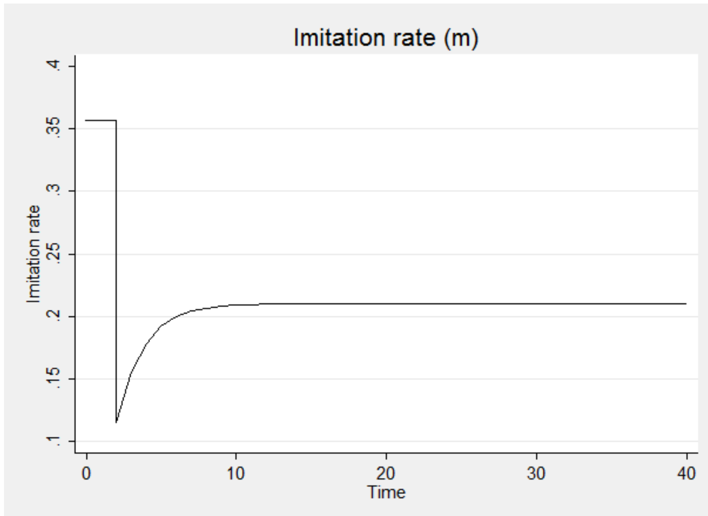
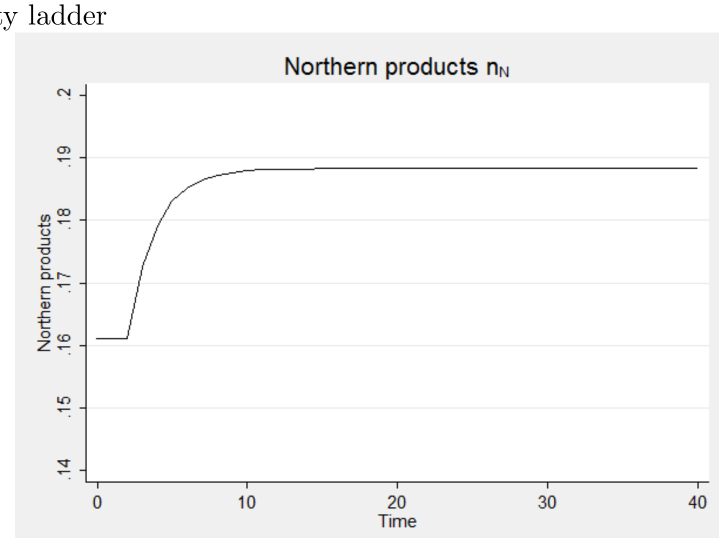


Figure G.3: Transition path for the fraction of products not imitated when imitation is endogenous - Quality ladder



Appendix H

Calculations for Chapter 3

This section is based on a simplified structure of the quality ladder model developed by Grossman and Helpman (1991a). Now the demand for each good is a constant fraction of world expenditure (there is no uncertainty about the demand like in Section 3.3) and firms are practicing limit pricing rather than profit maximizing prices.

A Northern firm has to choose between performing R&D at home, forming a joint venture with an existing Southern firm and purchasing R&D from a Southern firm. The trade-offs between these three organizational choices and the imitation probabilities (in case of offshoring) are modeled as in Section 3.3.

A firm that successfully performed R&D resulting in an innovation engages in limit pricing, setting a price equal to $p_N = \lambda \mathrm{w}_S$, and $j = N, S$. Consumers spread their consumption expenditure evenly across goods. Normalizing the world expenditure at each point in time to be one, the demand for each good is: $\mathrm{x}_j = 1/p_j$, $j = N, S$.

A Northern firm that successfully performs R&D at home, will earn the following profits:

$$\pi_H = (p_N - \mathrm{w}_N)x_N = \frac{\lambda \mathrm{w}_S - \mathrm{w}_N}{\lambda \mathrm{w}_S} = 1 - \frac{\mathrm{w}_N}{\lambda \mathrm{w}_S} \tag{H.1}$$

A Northern firm that creates a joint venture with a Southern firm in order to perform the same R&D activity as above, will earn the following profits:

$$\begin{aligned} \pi_{JV} &= (1-\mu)(p_N - \mathrm{w}_S)x_N - F = \frac{(1-\mu)(\lambda \mathrm{w}_S - \mathrm{w}_S)}{\lambda \mathrm{w}_S} - F = \\ &= (1-\mu)(1 - 1/\lambda) - F \end{aligned} \tag{H.2}$$

A Northern firm that purchases R&D from a Southern firm will earn the following profits:

$$\begin{aligned}\pi_{BUY} &= (1-\gamma)(p_N - \mathrm{w}_S)x_N = (1-\gamma)(\lambda \mathrm{w}_S - \mathrm{w}_S)/(\lambda \mathrm{w}_S) = \\ &= (1-\gamma)(1-1/\lambda) \qquad \text{(H.3)}\end{aligned}$$

A Northern Firm will choose to create a joint venture over performing R&D at home if:

$$\begin{aligned}\pi_{JV} &> \pi_H \\ \frac{\mathrm{w}_N}{\mathrm{w}_S} &> 1 + \mu(\lambda - 1) + F\lambda \qquad \text{(H.4)}\end{aligned}$$

Weaker IPR (a higher probability of imitation μ) and a lower fixed cost required by the participation in the joint venture will require a bigger gap between Northern and Southern wage in order to have an incentive for collaboration. If the inequality holds as equality, then the Northern Firm is indifferent between creating a joint venture and performing R&D at home.

A Northern Firm will choose to buy R&D from the South over performing R&D at home if:

$$\begin{aligned}\pi_{BUY} &> \pi_H \\ \frac{\mathrm{w}_N}{\mathrm{w}_S} &> 1 + \gamma(\lambda - 1) \qquad \text{(H.5)}\end{aligned}$$

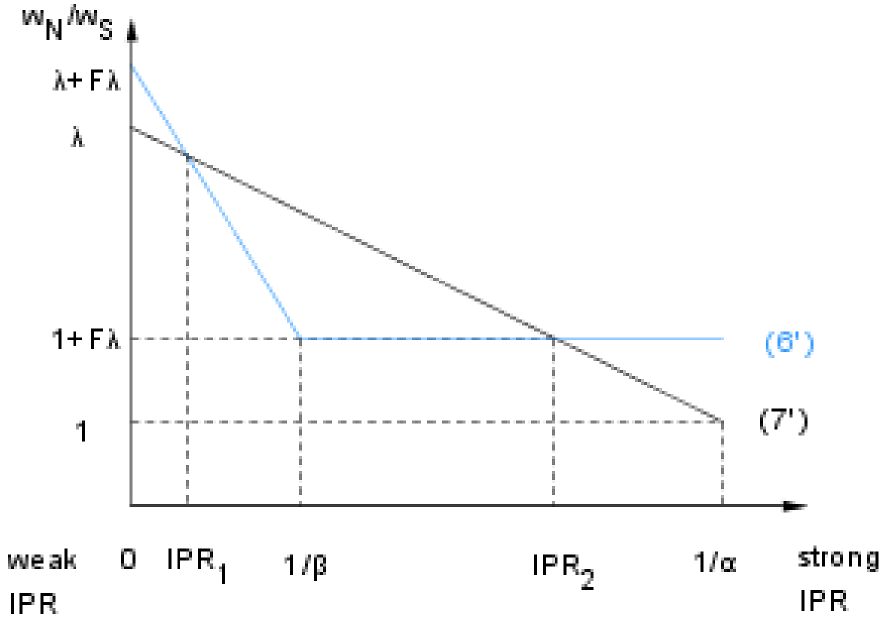
Weaker IPR (a higher probability of imitation γ) will require a bigger gap between Northern and Southern wage in order for the Northern firm to have an incentive to buy R&D from the South. If the inequality holds as equality, then the Northern Firm is indifferent between buying R&D from the South and performing R&D at home.

A Northern Firm will choose to create a joint venture over buying R&D from the South if:

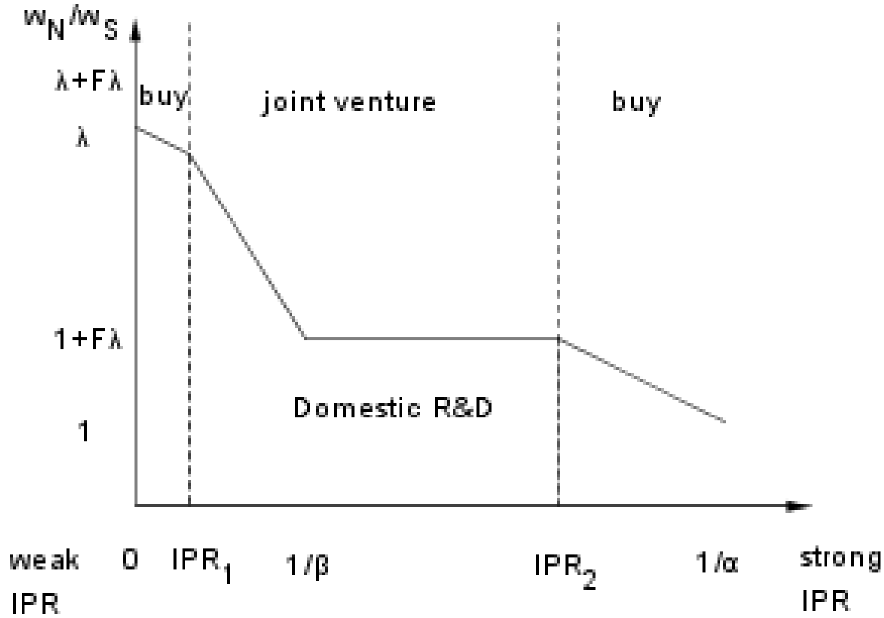
$$\begin{aligned}\pi_{JV} &> \pi_{BUY} \\ \gamma &> \mu + F/(1 - 1/\lambda) \qquad \text{(H.6)}\end{aligned}$$

When the two offshoring strategies face the same risk of imitation, the Northern firm will prefer to buy the R&D from the South (if it gives higher profits than doing research at home) because it avoids paying the fixed costs associated with joint venture. If the inequality holds as equality, then the Northern Firm is indifferent between creating a joint venture and buying R&D from the South. In order for joint venture to exist, the risk of imitation when buying the R&D (γ) has to be bigger than the risk of imitation when creating a joint venture (μ).

Equations (H.4) and (H.5) describe the conditions under which a Northern firm will prefer domestic R&D, forming a joint venture or buying R&D from the South. The strength of intellectual property rights will determine Northern firm action.



Below each of the lines, there is a combination of wage differential between North and South and the intensity of intellectual property rights that draw Northern firms to perform R&D at home. Above the black line, buying from a Southern firm will be preferred to domestic R&D. Above the blue line, forming a joint venture will be preferred to domestic R&D. Where the two lines intersect (IPR_1 and IPR_2), the Northern firm will be indifferent between domestic R&D, forming a joint venture and buying from a Southern firm. The lower envelope describe the border between preference towards domestic R&D and the other two activities.



For very weak IPR and big wage differential between North and South, Northern firms will choose to buy R&D from Southern firms. This way they will avoid paying the fix cost of forming a joint venture and take advantage of the wage gap between North and South (it has to be a big gap to offset the high risk of imitation). For stronger IPR and lower wage differential, Northern firms will choose to form joint ventures with Southern firms. It pays of for Northern firms to pay the fixed cost as they will face a lower risk of imitation in a joint venture than buying R&D from a Southern firm. For very strong IPR and very low wage differential, Northern firms will again choose to buy R&D from Southern firms. At this point, the probability of imitation in a joint venture is already zero while the risk of imitation from buying R&D is now low enough to outweigh the fixed cost of a joint venture.

Appendix I

Tables for Chapter 3

Table I.1: Description of variables

Variables	Definition
Partnership type	Is an indicator variable that takes value 1 if the relationship involved equity participation (joint venture) or 0 if there was no equity involved (from the SDC Platinum database for 89 countries over the period 1990 to 2009)
IPR protection in the destination country	The measure of a country intellectual property rights protection is based on the updated Ginarte and Park index presented in Park (2008)
Wage gap	This ratio measures the difference in the hourly wages (denominated in USD) across participating countries in a partnership (from the Yearbook of Labour Statistics and The International Yearbook of Industrial Statistics). It is the wage in the source country divided by the wage in the destination country
Wage gap squared	This is the previous ratio squared
Cost of doing business	This measures the number of days required in order to start a business in a country in a certain year. This index is reported by The World Bank Group starting in 2004. For the first part of the estimations, the 2004 value for each country is considered to be the value for the previous years as well
R&D flag	Is an indicator variable that takes value 1 if the agreement includes research and development services or 0 otherwise (from the SDC Platinum database)
Country dummies	These are 89 indicator variables that take value 1 if the firms belong to that country or 0 otherwise
Year dummies	These are 20 indicator variables that take value 1 if the agreement belongs to that year or 0 otherwise

Data is in constant USD, deflated by GDP deflator reported in the IMF database (base year 2005). The exchange rates used to transform hourly wages in USD came from the IMF database. Where available, wages are reported at three digits level: Chemical Manufacturing (NAICS 325), otherwise at the most detailed level available

Table I.2: Summary statistics

Variable	Mean	Std. dev.	Min.	Max.
Joint venture dummy	.3073903	.4614322	0	1
R&D dummy	.4323263	.4954202	0	1
IPR (Ginarte & Park index)	3.828589	1.093072	.59	4.88
Cost of doing business	29.94248	26.15059	2	168
Wage gap	8.87123	19.78742	.006064	186.255
Wage gap squared	470.2072	1893.636	.0000368	34690.93

Table I.3: Binomial Logit Estimation Results for the period 1990 - 2009 w/o R&D dummy

Variable	Base Model	with Cost of Business	with Country dummies	Country and Year dummies
	(1)	(2)	(3)	(4)
Constant	4.518814**	6.999832**	6.310232**	6.784791**
	(.1331988)	(.1888116)	(.5878757)	(.6131868)
IPR protection	-1.414687**	-1.830279**	-1.415384**	-1.573669**
	(.0325429)	(.0408832)	(.0601328)	(.0852544)
(marginal effects)	-.2001032**	-.2400521**	-.1676299**	-.1852207**
	(.0033201)	(.0038685)	(.0065958)	(.0095487)
WAGE Gap	-.0098146**	-.0040103*	-.000919	-.0018893
	(.0015594)	(.0016858)	(.0025638)	(.0026337)
(marginal effects)	-.0013882**	-.000526*	-.0001088	-.0002224
	(.0002197)	(.000221)	(.0003037)	(.00031)
Cost of business		-.0313948**	-.0184249**	-.0188402**
		(.0014035)	(.004307)	(.0048164)
(marginal effects)		-.0041176**	-.0021821**	-.0022175**
		(.0001732)	(.0005092)	(.0005659)
Number of obs.	11718	11718	11685	11685
Log likelihood	-5256.6435	-4943.8485	-4537.1391	-4516.8136

Notes:
*=significant at 10 percent
**=significant at 5 percent
Standard errors in parentheses

Table I.4: Cross tabulation of actual and predicted outcomes for the fourth specification

	JV flag		
JV flaghat	0	1	Total
0	7,507	1,216	8,723
	92.52	34.05	74.65
	64.24	10.41	74.65
0	607	2,355	2,962
	7.48	65.95	25.35
	5.19	20.15	25.35
Total	8,114	3,571	11,685
	100.00	100.00	100.00
	69.44	30.56	100.00

Table I.5: Binomial Logit Estimation Results for the period 1990 - 2009 with R&D dummy

Variable	Base Model	with Cost of Business	with Country dummies	Country and Year dummies
	(1)	(2)	(3)	(4)
Constant	4.17263**	6.765199**	6.252342**	6.753488**
	(.1353947)	(.192195)	(.5884544)	(.6148474)
IPR protection	-1.398758**	-1.846205**	-1.493529**	-1.660005**
	(.0326636)	(.0417809)	(.0606583)	(.0857063)
(marginal effects)	-.1944687**	-.237611**	-.1738332**	-.1917825**
	(.0032999)	(.0038836)	(.0064807)	(.009375)
WAGE Gap	-.0108747**	-.0057761**	-.0019822	-.0032225
	(.0015328)	(.0016506)	(.0025514)	(.0026206)
(marginal effects)	-.0015119**	-.0007434**	-.0002307	-.0003723
	(.0002121)	(.0002123)	(.000297)	(.0003027)
Cost of business		-.0322806**	-.0185312**	-.0202753**
		(.0014207)	(.0043486)	(.0048706)
(marginal effects)		-.0041546**	-.0021569**	-.0023424**
		(.0001715)	(.0005052)	(.0005616)
R&D dummy	.6353136**	.7214194**	.7799928**	.8091663**
	(.0496534)	(.051882)	(.0610994)	(.0617486)
(marginal effects)	.0883274**	.0928484**	.0907841**	.093484**
	(.006787)	(.0065691)	(.0070301)	(.0070494)
Number of obs.	11718	11718	11685	11685
Log likelihood	-5174.6932	-4846.3537	-4454.4574	-4429.558

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Table I.6: Cross tabulation of actual and predicted outcomes for the fourth specification

	JV flag		
JV flaghat	0	1	Total
0	7,528	1,271	8,799
	92.78	35.59	75.30
	64.42	10.88	75.30
0	586	2,300	2,886
	7.22	64.41	24.70
	5.01	19.68	24.70
Total	8,114	3,571	11,685
	100.00	100.00	100.00
	69.44	30.56	100.00

Table I.7: Binomial Logit Estimation Results including the Wage Gap squared and w/o R&D dummy

Variable	Extended Model (1)	with Cost of Business (2)	with Country dummies (3)	Country and Year dummies (4)
Constant	4.443959**	6.839247**	6.356433**	6.826559**
	(.1407995)	(.1914344)	(.5947992)	(.6209231)
IPR protection	-1.400313**	-1.798766**	-1.420642**	-1.578348**
	(.0336685)	(.0413156)	(.0610586)	(.0859988)
(marginal effects)	-.1980173**	-.2355238**	-.1682538**	-.1857686**
	(.003565)	(.0039935)	(.0067125)	(.0096377)
WAGE gap	-.0053071	.0084577**	-.004056	-.0045503
	(.0032375)	(.0034236)	(.0066245)	(.0067341)
(marginal effects)	-.0007505	.0011074**	-.0004804	-.0005356
	(.0004577)	(.0004479)	(.0007846)	(.0007926)
WAGE gap squared	-.0000465	-.0001254**	.0000245	.0000206
	(.000029)	(.0000298)	(.000048)	(.0000483)
(marginal effects)	-0.00000657	-.0000164**	0.0000029	0.00000243
	(0.0000041)	(0.00000389)	(0.00000568)	(0.00000568)
Cost of business		-.0319364**	-.0182742**	-.0187548**
		(.0014105)	(.0043176)	(.0048206)
(marginal effects)		-.0041816**	-.0021643**	-.0022074**
		(.0001735)	(.0005104)	(.0005664)
Number of obs.	11718	11718	11685	11685
Log likelihood	-5255.403	-4935.1969	-4537.006	-4516.7207

Notes:

*=significant at 10 percent

**=significant at 5 percent

Standard errors in parentheses

Table I.8: Binomial Logit Estimation Results with Wage Gap squared and R&D dummy

Variable	Extended Model (1)	with Cost of Business (2)	with Country dummies (3)	Country and Year dummies (4)
Constant	4.189919**	6.686131**	6.365587**	6.875556**
	(.1432104)	(.195475)	(.596123)	(.6235884)
IPR protection	-1.402336**	-1.82912**	-1.50692**	-1.674661**
	(.0340688)	(.0424734)	(.061807)	(.086735)
(marginal effects)	-.1949676**	-.235286**	-.1753793**	-.1934522**
	(.0035614)	(.0040388)	(.0066189)	(.0094915)
WAGE gap	-.0119778**	.0004405	-.0094788	-.0107228
	(.0033307)	(.0034786)	(.0067068)	(.0068318)
(marginal effects)	-.0016653**	.0000567	-.0011032	-.0012387
	(.0004626)	(.0004475)	(.0007805)	(.0007891)
WAGE gap squared	.0000113	-.0000617**	.0000583	.0000578
	(.0000304)	(.0000302)	(.0000488)	(.0000491)
(marginal effects)	0.00000157	-0.00000794**	0.00000679	0.00000668
	(0.00000422)	(0.00000388)	(0.00000568)	(0.00000568)
Cost of business		-.0325192**	-.0182264**	-.0201068**
		(.0014259)	(.0043573)	(.004873)
(marginal effects)		-.0041831**	-.0021212**	-.0023227**
		(.000172)	(.0005062)	(.0005618)
R&D dummy	.6381585**	.7052092**	.7839592**	.8134205**
	(.0502345)	(.0524925)	(.0611846)	(.0618548)
(marginal effects)	.0887235**	.0907135**	.0912392**	.0939641**
	(.0068691)	(.0066502)	(.0070388)	(.0070603)
Number of obs.	11718	11718	11685	11685
Log likelihood	-5174.6233	-4844.3171	-4453.7128	-4428.8377

Notes:
*=significant at 10 percent
**=significant at 5 percent
Standard errors in parentheses

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