International Protection of Intellectual Property: A Quantitative Assessment

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Abstract

The strength of intellectual property right (IPR) protection varies across countries and these differences have persisted across time. In this paper, I build a multi-country dynamic model where governments choose IPR policies each period. I use country heterogeneity in education, population, and bilateral trade costs to induce IPR protection choices and firm productivity distributions consistent with the data. I compare the benchmark open economy model to a model without trade and find that the latter generates a similar rank-ordering of country IPR choices, but IPR choices decrease 2%, on average. I also show that imposing government commitment decreases IPR choices substantially. Finally, I ask who wins and who loses under a harmonized IPR standard? To answer this, I compare the benchmark model to a planner's solution where the planner chooses and commits to a single IPR policy for all countries. I find the planner's IPR policy is significantly lower than the benchmark US policy. Though average country welfare decreases, developed countries are largely better off.

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1 Introduction

A country's level of intellectual property right (IPR) protection[1] reflects an important connection between government policy and firm innovation. Data indicates that countries choose different levels of protection and these differences have largely persisted across time.

While theory papers such as Helpman (1993) and Grossman and Lai (2004) have provided valuable qualitative insight into the driving forces behind country IPR decisions, little has been done to quantify the effects of IPR protection. The objective of this paper is to fill this void. Specifically, I ask two questions. First, what is the effect of trade on country IPR choices? Second, who wins and who loses under a global IPR standard?

To answer these questions, I develop a multi-country dynamic game in which countries choose their level of IPR protection each period. The model is a hybrid of firm R&D models à la Ericson and Pakes (1995) and international trade models à la Melitz (2003). Firms are heterogeneous in productivity and conduct R&D each period to stochastically increase their productivity level. These decisions generate an endogenous firm productivity distribution. Before the firms make their R&D decisions, governments simultaneously choose their IPR policy to maximize consumer welfare. Here, welfare maximization is closely related to maximizing the firm productivity distribution. I assume that government IPR choices affect firm transition probabilities directly, but there is a trade-off. High IPR (i.e., strong IPR protection) allows higher productivity firms to push out the technological frontier, while low IPR enables lower productivity firms to catch-up via an endogenous technological spillover. There also exists a time consistency issue where high IPR today increases technological spillovers in the next period, causing the government to deviate and choose low IPR in that period.

This paper represents a contribution on three fronts. First, I extend the work of Helpman (1993) and Grossman and Lai (2004) to develop a tractable and quantitative model of endogenous government IPR protection. In contrast to these papers, the correlation between firm innovation/ R&D and IPR protection is not necessarily positive; a result consistent with empirical studies. I use country differences education, population, and bilateral trade costs to induce equilibrium IPR choices consistent with the data.

[1] For the purpose of this paper, IPR encompasses fundamental issues such as the definition of a patent right, the duration of that right, breadth of patentability, viability of enforcement institutions, penalties for infringement, etc.

Secondly, the model is sufficiently tractable to answer the above important questions. I find that equilibrium IPR choices in a model without trade are 2% lower than the benchmark open economy model. I also compute the welfare effects of IPR harmonization. I compare the benchmark model to the solution of a planner's problem, where the planner maximizes country welfare around the world by choosing and committing to a single IPR standard. I find that the planner's IPR policy is 45% below the benchmark US IPR policy and that average country welfare decreases. Interestingly, developed countries are largely better off, while developing countries are worse off.

Thirdly, the model quantifies the effect of government commitment. I compare the benchmark model to a model where governments choose IPR at the beginning of time and commit to those choices. I find that imposing government commitment decreases equilibrium IPR protection substantially.

The paper proceeds as follows: the next sections provide facts from the data and review relevant literature. I outline the model in Section 4. I discuss parameters used to compute the model in Section 5, and describe the computational methods employed in Section 6. I present the model's results in Section 7. I conduct counterfactual policy experiments in Section 8 and compare the results with the benchmark model. I provide concluding remarks in Section 9.

2 A Look at the Data

While the topic of intellectual property rights is a heated and complex issue, there are several overriding themes in the data.

Data Fact 1: Countries choose their own level of IPR protection

First, and foremost, countries choose their own level of IPR protection and the data indicates that they choose different levels of protection.

Figure 1: **Mean IPR Protection Across the World (1960-1990)**

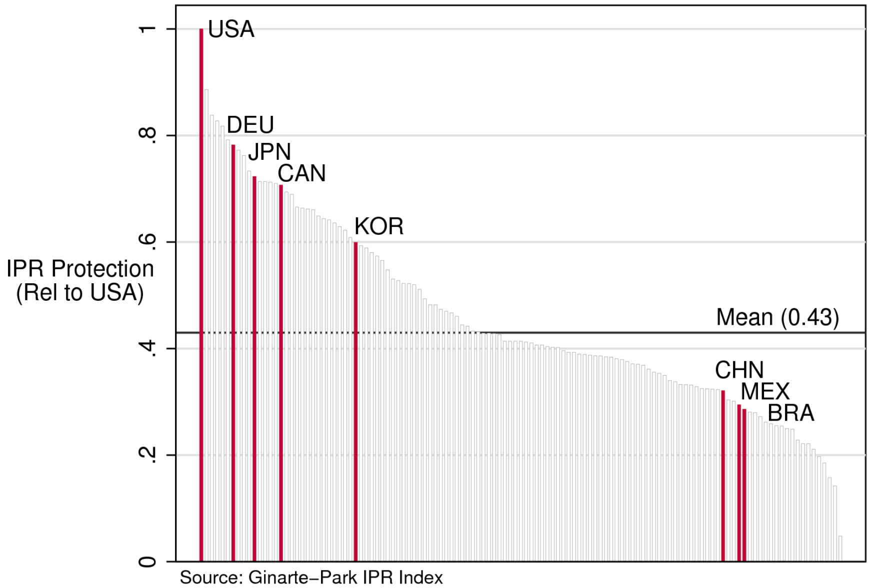


Figure 1 presents the cross-section of mean level of country IPR protection (relative to the US) between 1960 and 1990.[2] The level of IPR protection is measured using the index developed by Ginarte-Park. The index measures the strength of a country's patent regime is according to its "(1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection."

Protection in the US is substantially greater than even the contemporary developed and innovative countries like Germany (DEU) and Japan (JPN). Imitative countries like China and Brazil, not surprisingly, have low levels of protection. The figure also demonstrates the great deal of heterogeneity amongst countries.

Data Fact 2: Country IPR decisions do not vary across time

The data also indicates that countries generally don't change their level of IPR protection. Table 1 presents key moments from the Ginarte-Park index over time. For simplicity, all moments are computed relative to US IPR standards.[3]

[2] I chose to end the sample at 1990 so as to avoid any effects of patent harmonization due to the 1995 Uruguay Trade Round. Specifically, the agreement detailed in Annex 1C: Trade-Related Aspects of Intellectual Property Rights (TRIPS)

[3] This normalization does not materially affect the results since US IPR policies changed little over the period. The lone exception is a small increase in IPR protection during the 1980s related to the formation of the Court of Appeals for the Federal Circuit which centralized patent enforcement in the US.

Table 1: Protection Over Time (Rel to USA)

Year	Mean	Std Dev	Min
1960	0.46	0.17	0.05
1965	0.47	0.18	0.05
1970	0.48	0.18	0.05
1975	0.48	0.18	0.05
1980	0.46	0.18	0.05
1985	0.44	0.18	0.04
1990	0.45	0.20	0.04
1995	0.54	0.21	0.04
2000	0.63	0.21	0.04
2005	0.69	0.18	0.04
Number of countries: 51			

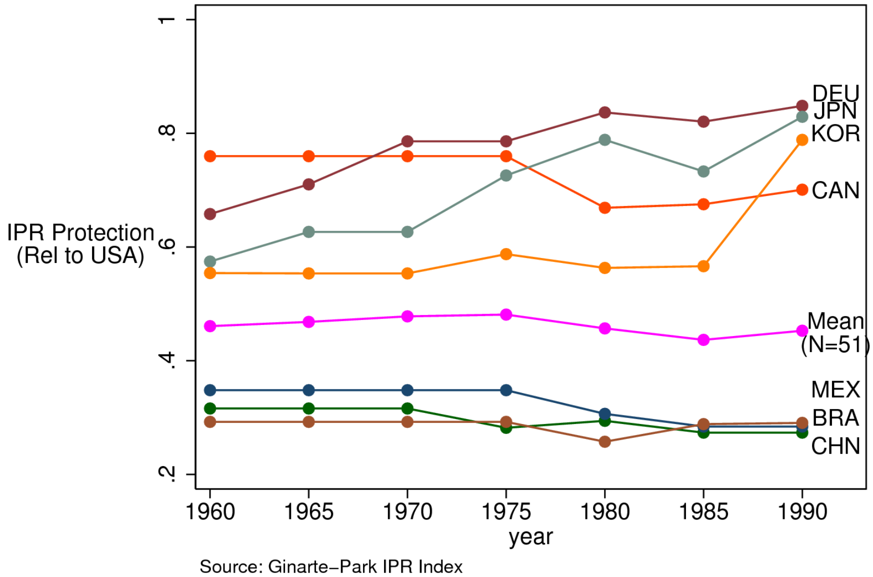
red indicates post TRIPS implementation

The "harmonization" of patent protection related to the TRIPS accord of the Uruguay trade round is reflected in years 2000 and 2005 where average IPR protection increased dramatically.[4] While the TRIPS accord didn't require countries to match US standards, it did mandate a non-trivial minimum level of IPR protection. For many developing countries, this amounted to a substantial increase in the breadth and enforceability of patent-related laws, as well as the strength of institutions charged with enforcing those laws. It's important to note that TRIPS was only one component of the Uruguay trade round and is largely seen as a concession by developing countries in exchange for favorable tariff reductions. Since this paper is concerned with generating endogenous IPR choices consistent with the data, I'll focus on the IPR decisions made prior to TRIPS (i.e., 1960-1990).

While most countries have continued to choose the same level of protection throughout the sample period, countries like Germany, Japan, and Korea increased their level of protection.

[4] While developed countries weren't required to adhere to the new IPR standards until 1996, one could argue that countries began modifying their IPR policies in preparation. As such, TRIPS likely affected IPR standards observed in 1995.

Figure 2: **IPR Protection Across Time (1960-1990)**



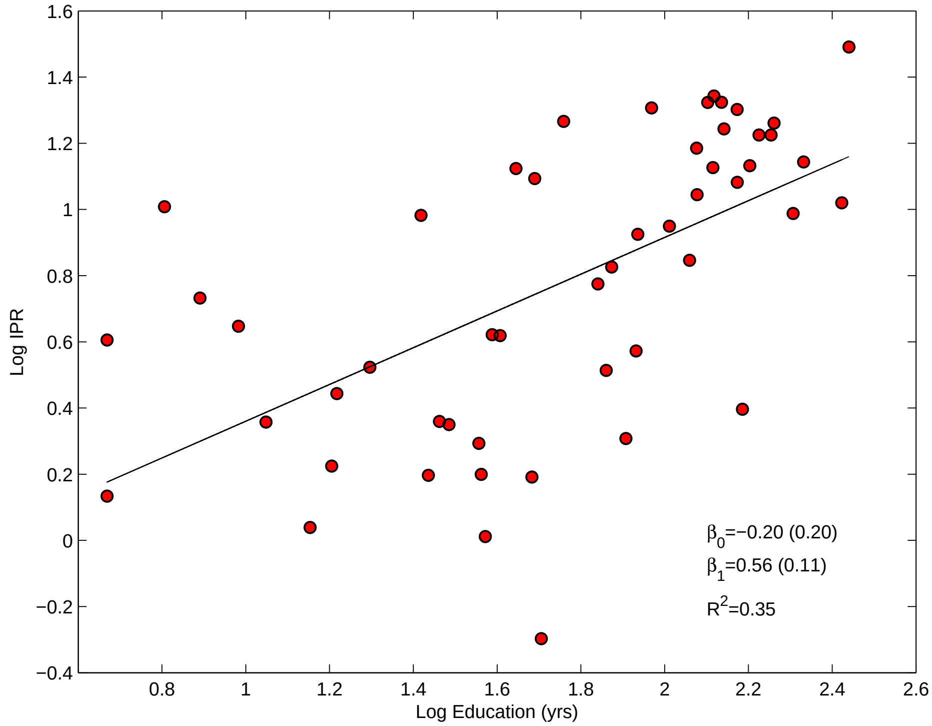
All three of these countries experienced rapid development during the sample period. Moreover, the observed increase in protection coincides with each country's development.[5] While the goal of this paper is not to explain these transitions from low to high IPR, the model does provide a framework to address these transitions and is an interesting topic for future work.

Data Fact 3: IPR decisions are increasing in education and real GDP

Figure 3 compares the log years of education in each country to log IPR.

[5] Unfortunately, the Ginarte-Park index data is aggregated so I can't see what specific policy changes led to the observed increases.

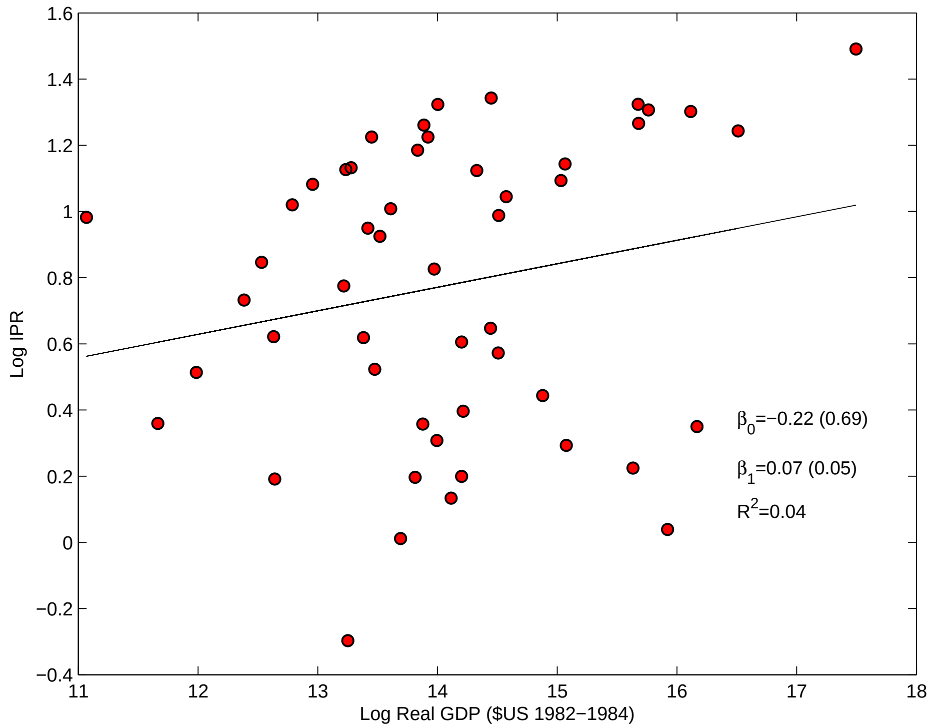
Figure 3: **Education and IPR**



The correlation is positive ($\beta_1 = 0.56$) and statistically significant. Moreover, the relationship between protection and education is robust to other education measures.[6] Figure 4 compares log GDP to log IPR.

[6] For example, percentage of total population completing secondary/ post-secondary education.

Figure 4: **GDP and IPR**



Again, the correlation is positive ($\beta_1 = 0.07$), though not statistically significant.

Data Fact 4: Countries apply IPR protection uniformly to imported goods

The 1883 *Paris Convention for the Protection of Industrial Property* represents the most fundamental treaty on patent protection[7] and requires signatories to apply its laws equally to all goods in the country. The doctrine of "national treatment" is outlined specifically in Article 2:

> Nationals of any country of the Union shall, as regards the protection of industrial property, enjoy in all the other countries of the Union the advantages that their respective laws now grant, or may hereafter grant, to nationals; all without prejudice to the rights specially provided for by this Convention.

National treatment means that governments cannot assign different levels of protection to goods from different countries.[8] This represents an important departure from tariffs and simplifies the model significantly.

[7] All the countries in my sample have signed this treaty.

[8] There is some evidence that countries may deviate from this doctrine. For example, the time required to obtain a patent in a developing country is said to be longer for foreign firms. Since I don't observe any compelling evidence to suggest systematic discrimination, I assume these instances are sufficiently small.

3 Related Literature

The literature related to IPR protection is large, hence I will only address the most relevant papers here.[9] The model is most closely related the Grossman and Lai (2004). In their paper, governments choose the level of protection so as to minimize prices and maximize variety. They show that equilibrium IPR protection is increasing in education and market size, which is consistent with the above data facts. Lai (2009) adds trade costs to this set-up and asks whether an internationally coordinated IPR standard would be too weak. Both papers assume that government can commit to its IPR policy.

This paper differs from Grossman and Lai (2004) in a number of ways. First, this paper aims to quantify the effects of IPR protection, thereby extending some of the theoretical insights presented by Grossman and Lai (2004). Second, I model the trade-off between high and low IPR protection differently. Grossman and Lai (2004) model protection as patent length and assume the good is costlessly imitated upon patent expiration. Once imitated, competition drives the good's price down to marginal cost. Increasing patent length then increases the number of varieties, as well as prices. Modeling the trade-off this way necessarily implies that innovation is strictly increasing in the level of IPR protection; a prediction disputed by several empirical studies.[10] An important result of this paper is that firm innovation/ R&D and IPR may not be positively correlated. Thirdly, I allow governments to deviate from their prescribed IPR policy choices. It turns out that allowing this level of flexibility has significant quantitative implications.

Acemoglu, Aghion, and Zilibotti (2003) show that less technologically advanced countries choose lower levels of protection in order to catch up to the rest of the world. In my model, firms gain technological spillovers from both domestic and foreign firms. Bilateral trade costs limit these spillovers. The model generates equilibrium IPR protection choices consistent with their prediction.

Acemoglu and Akcigit (2008) explore the potential benefits of state-dependent IPR protection relative to the current uniform standard. They fit a benchmark model to aggregate moments of the US distribution and show that a state-dependent IPR standard can generate additional welfare. My model is sufficiently tractable to conduct counterfactual experiments to ascertain the welfare effects of international harmonization to US protection standards, as well as the socially optimal global standard. In contrast to Acemoglu and Akcigit (2008), both experiments are based on a state-independent policy standard, which is consistent with IPR

[9] For a more comprehensive review see Maskus (2000).

[10] See Boldrin and Levine (2008) for a comprehensive review.

standards observed in the data.

4 Model

The model is a hybrid of firm R&D similar to Ericson and Pakes (1995) and international trade similar to Melitz (2003). Firms are heterogeneous in their level of productivity. They enter the period with a specific productivity level and compete with other firms in a spot market. Firm profit is increasing in a firm's own productivity level and competitor prices. At the conclusion of the spot market, incumbent firms exit the industry at an exogenous rate. Government then makes an IPR decision and surviving incumbent firms conduct R&D to stochastically improve their productivity. The government's choice of IPR affects firm transition probabilities directly, but there exists a trade-off. Under a high IPR choice, high productivity firms push out the technological frontier. Under a low IPR choice, low productivity firms catch-up via an endogenous technological spillover. Entering firms pay a fixed cost of entry and receive their initial productivity draw from a potentially country-specific but time-invariant distribution.

4.1 Environment

4.1.1 Households

Time is discrete and the horizon is infinite. To simplify notation, I suppress time subscripts and note when inter-temporal issues exist. There are N countries indexed by $i = 1, \ldots, N$. Each country is endowed with a level of education H_i and L_i consumers. Each agent is endowed with a unit of time. Agents in all countries have identical preferences over two types of goods. The first is a homogeneous, freely traded good M produced with a constant returns production technology that uses one unit of labor input per unit of output. The second is a composite good produced with a set of differentiated goods. In particular, each consumer has the following Cobb-Douglas preferences:

$$\begin{aligned} U_i &= M_i^{1-\eta}\left[\sum_{j\in J_i} q_{i,j}^{\alpha}\right]^{\frac{\eta}{\alpha}} \\ & \quad \alpha, \eta \in (0,1) \end{aligned} \tag{1}$$

where j denotes a product variety and J_i is the set of all product varieties available in country i. The parameters α and η are common to all countries. This set-up implies that the demand for good j in country

i is:

$$q_{i,j} = \frac{p_{i,j}^{-\epsilon}}{P_i^{1-\epsilon}} \cdot \eta Y_i$$
$$\epsilon = 1/(1-\alpha)$$

where ϵ is the elasticity of substitution between differentiated goods and ηY_i is aggregate spending on differentiated goods in country i. P_i is the price index for country i, defined as:

$$P_i = \left[\sum_{j \in J_i} p_{i,j}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$$

4.1.2 Firms

Firms produce goods using only labor (l), which the economy supplies inelastically at wage rate w_i. Without loss of generality, I assume factor price equalization via M and normalize the wage rate to one for all countries (i.e., $w_i = 1 \ \forall i$). Firms are heterogeneous in unit labor productivity (x) and supply goods according to the following linear production function:

$$q_{i,j} = x_{i,j} \cdot l_{i,j}$$

where productivity level x lies in the discrete, compact set X. All production for a firm from country i occurs in country i, though the firm may choose to sell goods in other countries. Similar to Melitz (2003), all firms from country i selling goods in country n incur a per-unit bilateral iceberg trade cost $\tau_{ni} \geq 1$. These costs capture the cost related to transporting goods from country i to country n. Without loss of generality, normalize $\tau_{ii} = 1 \ \forall i$. There are no fixed costs of trade so the set of varieties available in each country is the same ($J_i = J \ \ \forall i$).

4.1.3 Governments

Each country i has a government which chooses a level of IPR protection γ_i each period. The country i government chooses γ_i to maximize the indirect utility of the consumers in country i (L_i).[11] Define $\gamma = [\gamma_1, ..., \gamma_N]$ as the vector of IPR decisions around the world. I assume that governments choose IPR protection simultaneously each period.

[11] An alternative mechanism would be to place different weight on firm profits and consumer welfare. Since ex ante there is no way to discipline these weights with data, I leave this alternative objective function as an area for future research.

4.2 Spot Markets

Similar to Ericson and Pakes (1995), I assume competition in the country n differentiated good sector occurs in a spot market at the beginning of each period. Hence, firm j from country i with productivity x solves the following static pricing problem in country n:

$$\max_{p_{j,ni}} \left[p_{j,ni} - \frac{\tau_{ni}}{x} \right] \frac{p_{j,ni}^{-\epsilon}}{P_n} \tag{2}$$

I assume that firms are sufficiently small such that $\frac{\partial P_n}{\partial p_{j,ni}} = 0$. Optimal pricing is then only a function of the firm j's productivity level and the trade costs.

$$p_{j,ni} = \frac{\tau_{ni}}{\alpha x} \tag{3}$$

Since firms enter symmetrically into equation (1) and are differentiated only by their level of productivity, it is convenient to refer to good j by its productivity x. Henceforth I will refer to "good x" rather than "good j." Define $\mu_i(x)$ as the mass of country i firms with productivity x where $\mu = [\mu_1, ..., \mu_N] \in \mathcal{M}$ is the vector of firm productivity distributions across the world. I can then rewrite the price index in country n as

$$P_n(\mu) = \left[\sum_{i=1}^{N} \sum_{x \in X} p_{ni}(x)^{1-\epsilon} \mu_i(x) \right]^{\frac{1}{1-\epsilon}}$$

Profit for a firm from country i with productivity x in country n is then

$$\pi_{ni}(x, \mu; \tau_{ni}) = x^{\epsilon - 1} \left[\frac{\tau_{ni}}{\alpha P_n(\mu)} \right]^{1-\epsilon} (1-\alpha)\eta Y_n$$

Firm profits are increasing in the level of productivity and competitors' prices (as captured through the price index), but are decreasing in the bilateral iceberg transportation costs.

Equilibrium Definition: Given state μ, a spot market equilibrium in country n is a set of

1. Demand functions:

$$q_{ni}(x) = \frac{p_{ni}(x)^{-\epsilon}}{[P_n(\mu)]^{1-\epsilon}} \cdot \eta Y_n$$

2. Price functions:

$$p_{ni}(x) = \frac{\tau_{ni}}{\alpha \cdot x}$$

3. Profit functions:

$$\pi_{ni}(x,\mu;\tau_{ni}) = x^{\epsilon-1}\left[\frac{\tau_{ni}}{\alpha P_n(\mu)}\right]^{1-\epsilon}(1-\alpha)\eta Y_n$$

Such that aggregate spending equals aggregate income:

$$Y_n = L_n + \Pi_n$$

where Π_n is the aggregate profit of country n firms. The last condition is a market clearing condition which connects population to aggregate spending (market size).

4.3 Research and Development

Similar to Ericson and Pakes (1995) and Atkeson and Burstein (2009), firms can stochastically improve their productivity level by conducting R&D. After profits are realized, firms maximize the net present value of profit flows by choosing how much to invest in research and development. Define $\iota(x)$ as the research and development investment of a firm with productivity x. Following Ericson and Pakes (1995), I model the research process for a firm with productivity $x = x^k \in X$ using the following functional form:

$$F(x'|x,\iota\cdot R_i) = \begin{cases} \frac{R_i\cdot\iota}{1+R_i\cdot\iota} & x' = x^{k+1} \\ \\ \frac{1}{1+R_i\cdot\iota} & x' = x^{k-1} \end{cases} \tag{4}$$

where R_i parameterizes the transition function in country i, and country i firms take R_i as given. Note that $F(\cdot)$ is first-order stochastically increasing in R_i, the firm's current productivity level (x), and research investment (ι). The first is important for generating equilibrium IPR decisions observed in the data, while the latter two are desirable characteristics.[12]

Successful R&D results in a step improvement in labor productivity, while unsuccessful R&D results in a step reduction in firm productivity. This reduction in productivity could capture two effects. First is the notion of "organizational forgetting" documented by Benkard (2004) where production processes become inefficient. The second relates to the notion of Schumpetarian's creative destruction where firms are unable to keep up with competitors. Successful innovations by the competition decrease expected discounted profits and firm R&D. This imposes a negative externality on a single firm as it increases the likelihood of becoming

[12] An added benefit is that there exists a closed-form solution to the optimal investment decision. While not necessary for my results, this simplifies an already computationally-intensive model.

less competitive.

4.3.1 IPR Protection

Consistent with the data, each government chooses its own level of IPR protection. The IPR choice of a government in country i is defined as $\gamma_i \in [0,1]$. A country i with γ_i close to one is said to have high levels of protection (e.g., strong enforcement institutions). Importantly, the choice of γ_i is common to all firms in country i.

The IPR policy in country i impacts the transition probabilities for country i firms directly through the research parameter R_i. Specifically, I assume that R_i takes the following functional form:

$$R_i(x,\gamma,\mu) = [\gamma_i^b \mathrm{H}_i + (1-\gamma_i)^b S_i(x,\mu)]^{1/b} \tag{5}$$

$S_i(x,\mu)$ is an endogenous technological spillover for a country i firm with productivity x. Similar to Coe and Helpman (1995), technological spillovers occur via importing and I assume a similar functional form:

$$S_i(x,\mu) = \frac{\sum_{n=1}^{N} \omega_{in}\overline{\mu}_{in}}{x}$$

where $\overline{\mu}_{in}$ is the average productivity of firms from country n selling goods in country i and ω_{in} is the share of country n GDP corresponding to country i goods. Since there are no fixed costs in the model, all firms export and $\overline{\mu}_{in} = \overline{\mu}_n \;\; \forall n$.

The assumed functional forms for R_i and S_i exhibit some important properties. First, technological spillovers are decreasing in the firm's productivity. The intuition is that firms near the technological frontier "learn" very little from their less-advanced competitors. This assumption is similar to Eeckhout and Jovanovic (2002) and Yu (2008). Secondly, R_i is strictly concave in γ_i for all x. As I'll show in Section 4.4, this also generates concavity for the government's objective function. The parameter b is a curvature parameter and is common across all countries.

4.3.2 The Firm's Problem

Define the government decision rule for country i as $\Psi_i(\mu)$ and the vector of government decision rules as $\Psi = [\Psi_1, ..., \Psi_N]$. Define γ_{-i} as the vector of all the government IPR choices other than country i. For now,

Ψ is exogenous. I assume firms exit at an exogenous rate $1-\delta$, which is common to firms in all countries.[13] An incumbent firm in country i with productivity x and aggregate state (μ) chooses R&D (ι) to maximize discounted profits conditional on the law of motion for the aggregate state ($\Upsilon : \mathcal{M} \to \mathcal{M}$) and government decision rules (Ψ).

$$\begin{aligned} V_i(x,\mu) &= \sum_n \pi_{ni}(x,\mu;\tau_{ni}) + \delta \max_\iota [-\iota + \frac{1}{1+r} E_{F(x'|x,\iota\cdot R_i)} V_i(x',\mu')] \\ \text{s.t.} & \\ R_i &= [\gamma_i^b \mathrm{H}_i + (1-\gamma_i)^b S_i]^{1/b} \\ \gamma &= \Psi(\mu) \\ \mu' &= \Upsilon(\mu,\gamma_i,\gamma_{-i}) \end{aligned} \tag{6}$$

4.3.3 Entry

Outside firms may choose to enter the industry and do so only if the expected discounted value of entry is greater than the country i fixed cost of entry (f_i^e). Entering firms in country i draw their initial productivity level from a time-invariant cdf G_i. Conditional on aggregate state the (μ), government decision rules (Ψ), and the law of motion (Υ), a prospective firm in country i chooses entry if and only if

$$\begin{gathered} \frac{1}{1+r} \cdot E[V_i(x',\mu')|G_i] \geq f_i^e \\ \text{s.t. } \gamma = \Psi(\mu) \\ \mu' = \Upsilon(\mu,\gamma) \end{gathered} \tag{7}$$

Define the function $e_i(\mu)$ as the firm entry rate in country i, then Υ for country i is

$$\mu_i(x') = \delta \sum_{x\in X} F(x'|x,\iota_i \cdot R_i)\mu_i(x) + G_i(x')e_i$$

4.3.4 The Government's Problem

Now I'll endogenize the level of protection. I assume that governments choose their IPR policies simultaneously after firm profits are realized but before firms make their R&D decisions. Consistent with national treatment, governments choose a single IPR policy.[14] I assume governments choose IPR to maximize welfare

[13] One could also endogenize exit similar to Ericson and Pakes (1995), Atkeson and Burstein (2009) and Weintraub, Benkard, and Van Roy (2008).

[14] In other words, I don't allow governments to choose different IPR standards for goods coming from different countries

in their country.

$$W_i(\mu) = \max_{\gamma_i} \{U_i(\mu) + \beta W(\mu')\} \tag{8}$$

where $U_i(\mu)$ is the indirect utility function of country i associated with aggregate state μ.

Feasibility in the labor market requires that

$$L_i = L_i^M + e_i f_i^e + \sum_{x \in X} [l_i(x) + \iota_i(x)] \, \mu_i(x)$$

where L_i^M denotes total employment in production of the homogeneous good M, $\sum_{x \in X} l_i(x)\mu_i(x)$ is the total labor employed in the production of differentiated goods, $\sum_{x \in X} \iota_i(x)\mu_i(x)$ is total employment in research, and $e_i f_i^e$ is the total employment used to create entering firms.

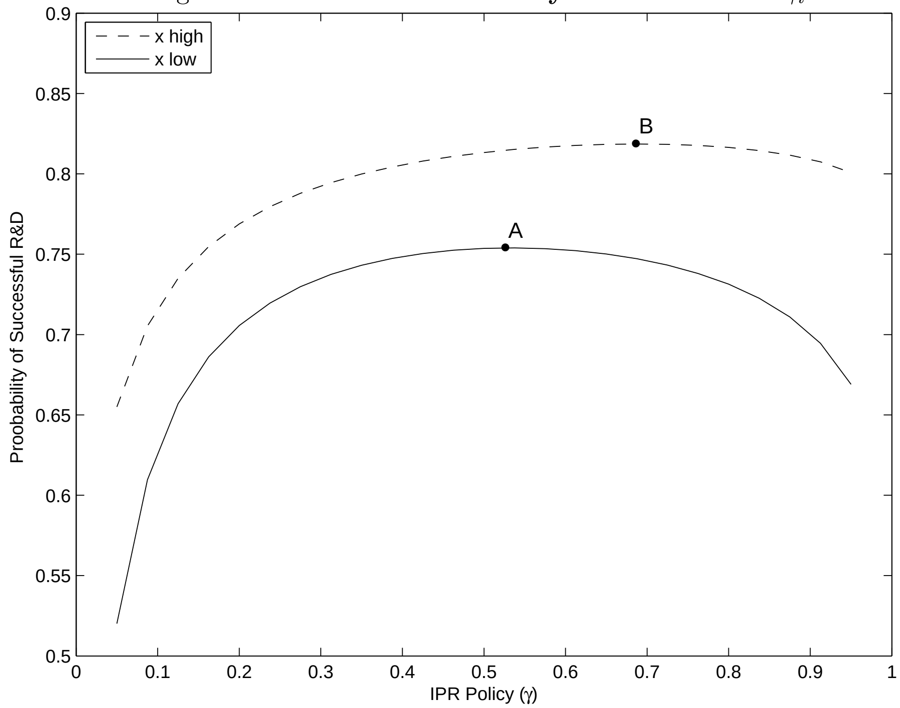
It is important to note that firm decision rules (ι_i, l_i, e_i) depend both on the government's IPR choice (γ_i) and the law of motion for the measure of operating firms Υ, where

$$\mu' = \Upsilon(\mu, \gamma_i, \gamma_{-i})$$

4.4 Equilibrium

Before defining the equilibrium and proving existence, it's instructive to explore some the mechanics of the model. For heuristics, fix μ and consider the effect of different IPR policies on incumbent firms. Recall the transition function F is increasing in $R_i \cdot \iota$, where R_i is strictly concave in γ_i for all x. Figure 5 presents the different effects of a single γ_i on firms with different productivity states.

Figure 5: **Transition Probability Conditional on γ_i**



The points A and B define the greatest probability of transitioning to a higher productivity level for firms with low and high productivity, respectively. The figure demonstrates a crucial implication of the model. If government chooses a high IPR ($\gamma_i \to 1$), the high productivity firm will likely increase its productivity state, but the low productivity firm likely will not. The former result is consistent with the traditional way to model IPR protection: higher IPR generates more productive firms (i.e., more "innovation"). The intuition behind this latter result is that a high IPR limits the low productivity firm's ability to catch-up via the technological spill-over. The converse is true under the low IPR case. Hence, though application of IPR protection is independent of the firm's state (i.e., all firms observe the same γ_i), the result is not.

Let's now enlarge the set of firms.

Figure 6: **IPR Choices Conditional on μ_i**

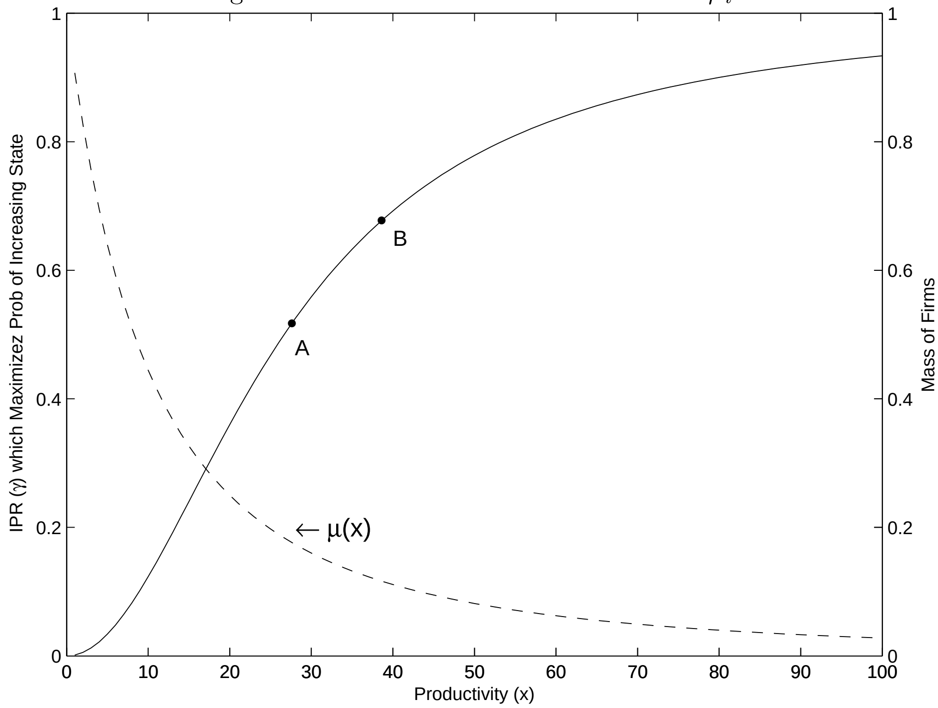
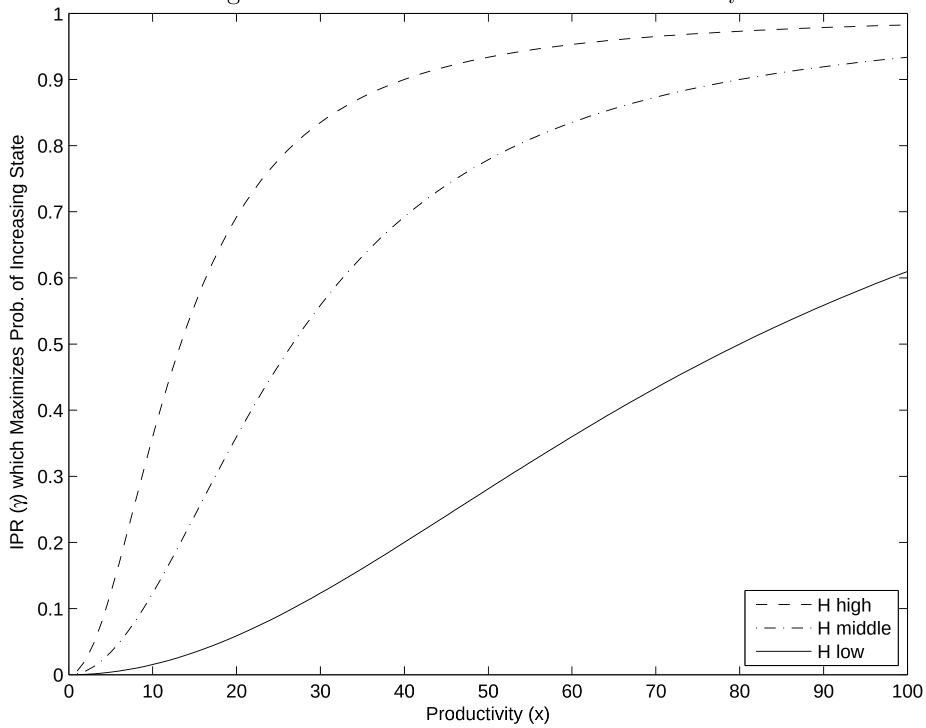


Figure 6 demonstrates the government's trade-off when considering the entire country i firm productivity distribution μ_i. The solid line represents the γ_i choice that maximizes each firm's (with respect to x) probability of increasing its productivity state. The government wants to maximize the entire firm productivity distribution, so it chooses the γ such that "average" firm productivity increases. An important implication is that firm productivity distribution is not stochastically increasing in the level of IPR chosen by the government. Hence, the correlation between firm "innovation" and IPR is not necessarily positive; a finding consistent with many empirical studies in the IO literature.

The model also generates the positive correlations discussed in Section 2. Figure 7 illustrates $\gamma(x)$ as a function of H_i

Figure 7: **IPR Choices Conditional on H_i**



In countries with higher levels of education, technological spillovers are relatively less important, so these countries choose higher levels of protection.

The correlation of IPR with market size is more subtle. Larger markets correspond to greater expected discounted profits for firms, hence greater R&D effort and more high productivity firms. In equilibrium, government is more likely to choose a higher IPR standard.

There are a couple additional things to note. First, I fixed μ to elucidate some fundamental interactions, but μ is, of course, an endogenous equilibrium object. Government IPR choices both are dependent upon μ, as well as drive its value. A steady-state equilibrium is then a fixed point between the two. Secondly, the concavity of the research function R_i (as implied by b) generates interior solutions to the government's problem, as well as a distribution of IPR decisions across the world. This is consistent with the data where no country in my data set has Ginarte-Park IPR scores of either five or zero.

4.4.1 Time Consistency

I allow governments to choose their level of protection each period. This presents an interesting time-consistency issue where a government in country i choosing high IPR protection induces high productivity firms to increase in productivity, thereby, likely increasing average productivity ($\overline{\mu}_i$) in the next period.[15] In the next period, the government may optimally choose a low level of protection to enable low productivity firms to "catch-up."

Providing this level of flexibility introduces a great deal of complexity to solving the model. Following Krusell, Quadrini, and Rios-Rull (1997) and Corbae, D'Erasmo, and Kuruscu (2009), I solve the government's problem by considering one-shot deviations from the prescribed policy choice. Call the deviation γ' and note that γ' may not necessarily equal $\Psi(\mu)$. Since this is a one-shot deviation, future values of protection do follow Ψ.

The deviation affects the firm research efforts and hence the law of motion for the aggregate state. The country i incumbent firm's problem is then

$$\begin{aligned} \tilde{V}_i(x,\mu,\gamma') &= \sum_n \pi_{ni}(x,\mu_n;\tau_{ni}) \\ &+ \delta \max_{\iota}[-\,\iota + \beta E_{F(x'|x,\iota\cdot\tilde{R}_i)} V_i(x',\mu')] \\ \text{s.t.} & \\ R_i(x,\gamma_i',\mu) &= \left[\mathrm{H}_i \gamma_i'^b + (1-\gamma_i')^b S_i(x,\mu)\right]^{1/b} \\ \gamma_{-i} &= \Psi_{-i}(\mu) \\ \mu' &= \tilde{\Upsilon}(\mu,\gamma_i',\gamma_i) \end{aligned} \tag{9}$$

where the tilde superscripts denote variables potentially affected by the deviation. Note that, consistent with a one-shot deviation, $V_i(\cdot)$ is from the solution to the incumbent firm's problem (6). The function $\tilde{\Upsilon}$ corresponds to the new law of motion and is a function of the deviation. Firm entry $\tilde{e}$ solves

$$\begin{gathered} \beta \cdot E[V_i(x',\mu')|G_i] \geq f_i^e \\ \text{s.t. } \mu' = \tilde{\Upsilon}(\mu,\gamma_i',\gamma_{-i}) \end{gathered} \tag{10}$$

where I assume G_i and f_i^e are invariant to the deviation, hence $\tilde{e}$ is only effected by $\tilde{\Upsilon}$.[16]

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[15] That is, if the government chose a high IPR, it is likely that it did so because this choice implied an increase in average firm productivity.

[16] This simplification is due to a lack of sufficient priors to discipline a more rigorous approach.

These decision rules then imply a one-shot deviation version for the country i government value function

$$\tilde{W}_i(\mu, \gamma') = \max_{\gamma'} \{U_i(\mu) + \beta \cdot W_i(\mu')\} \tag{11}$$

subject to the new law of motion $\mu' = \tilde{\Upsilon}(\mu, \gamma_i', \gamma_{-i})$ and feasibility[17]

$$L_i = L_i^M + \tilde{e}_i f_i^e + \sum_{x \in X} \left[\tilde{l}_i(x) + \tilde{\iota}_i(x)\right] \mu_i(x)$$

Equilibrium Definition: For every $\mu = [\mu_1, \mu_2, ..., \mu_N]$, an Open Economy Markov Perfect Equilibrium (OEMPE) is a set of decision rules $\{\iota_i, e_i, \Psi_i\}$ where:

i. the firm investment decision rule ι_i solves the incumbent firm's investment problem (equation 6) $\forall i$

ii. the mass of entering firms e_i implies expected discounted profits are zero (equation 7) $\forall i$

iii. the IPR decision rule Ψ_i solves the government's problem (equation 8) $\forall i$

Assumption 1 *There exists a sufficiently large set of prospective entering firms in each country such that there exists positive entry. Further, firms follow a mixed entry strategy, entering with weakly positive probability.*

The following proposition establishes the existence of equilibrium firm entry. I present the proof in the Appendix **??**, together with all other proofs.

Proposition 1 *Given assumption (1), firm entry follows a Poisson random variable. Moreover, there exists a cut-off mass of entering firms (e_i $\forall i$) such that $\beta \cdot E[V_i(x', \mu')|G_i] = f_i^e$.*

The following proposition characterizes the value function for an incumbent firm.

Proposition 2 *The incumbent firm value function exists, is unique, continuous, strictly increasing, and differentiable*

Finally, proposition 3 establishes existence of a OEMPE.

Proposition 3 *(Existence) There exists an equilibrium to the to the OEMPE.*

Proving uniqueness in this class of models is difficult, if not impossible. That said, the numerical algorithm I use appears resilient to different initial conditions.[18]

[17] Since the marginal productivity of the homogeneous good and wages are fixed, the amount labor allocated to this sector is also fixed.

[18] That is, starting from different starting values results in the same equilibrium.

4.4.2 Alternative Government Policy Mechanisms

The full model presented allows governments to deviate from any previous policy choice. I call this the "no commitment" model and view it as the benchmark model.[19] An alternative mechanism would be to assume that there does exist a government commitment technology. In this model, each government chooses a single IPR protection standard at the beginning of time and never deviates. Using the notation developed above, the optimal government policy for each country i is

$$\Psi_i^{com}(\mu) = \underset{\gamma'}{\text{argmax}}\, \tilde{W}_i(\mu, \gamma')$$

with future policy choices constrained by this choice $\gamma_i'' = \Psi_i(\mu) = \gamma_i'$.

5 Parameterization

The model presented depends on specifications for entry distributions $\{G_i\}$, bilateral trade weights and costs $\{\omega_{ni}, \tau_{ni}\}$, entry costs $\{f_i^e\}$, and parameters $\{\epsilon, \eta, b, \beta, \delta\}$.

5.1 Entry Distributions

Similar to Melitz (2003), I assume entering firms in all countries draw their initial productivity from the same Pareto distribution. Relaxing this assumption has little effect on the results. Further, there exists little cross-country evidence to provide much discipline on a more rigorous assumption.

5.2 Trade Weights and Costs

I use data on bilateral trade flows from Feenstra, Lipsey, Deng, Ma, and Mo (2005) to compute the weights $\{\omega_{ni}\}$ in the technological spillover function $S(x, \mu)$. I also use these data and accompanying country demographics[20] to estimate the iceberg trade costs τ_{ni}. Denote the total trade from country i to country n as T_{ni}, then the model implies the following form for trade:

$$T_{ni} = \sum_{x \in X} p_{ni}(x) q_{ni}(x) \mu_i(x) \tag{12}$$

[19] Unless explicitly noted, all analysis and counterfactual policies will be based on this model.

[20] See appendix for data sources.

Substituting equilibrium values for $p_{ni}(x)$ and $q_{ni}(x)$ equation (12) becomes

$$\begin{aligned}
T_{ni} &= \sum_{x\in X} p_{ni}(x)\left(\frac{p_{ni}(x)^{-\epsilon}}{P_n^{1-\epsilon}}\cdot \eta Y_n\right)\mu_i(x) \\
&= \sum_{x\in X} p_{ni}(x)^{1-\epsilon}\left(\frac{\eta Y_n}{P_n^{1-\epsilon}}\right)\mu_i(x) \\
&= \eta(w/\alpha)^{1-\epsilon}\tau_{ni}^{1-\epsilon}\left(\frac{Y_n}{P_n^{1-\epsilon}}\right)\sum_{x\in X} x^{\epsilon-1}\mu_i(x) \qquad (13)
\end{aligned}$$

Applying logs to equation (13), I get a gravity equation for trade flows:

$$t_{ni} = \text{constant} + (1-\epsilon)\ln(\tau_{ni}) + I_n + E_i$$

where $t_{ni} = \ln T_{ni}$ and (I_n, E_i) are importer and exporter fixed effects, respectively. Consistent with several papers in the trade literature, I assume the the trade costs take the following log-linear form:

$$\ln(\tau_{ni}) = \beta_{dist}\log(dist_{ni}) + \beta_{lang}lang_{ni} + \beta_{border}border_{ni} + \beta_{colony}colony_{ni}$$

where $dist_{ni}$ is the bilateral distance between countries n and i. As distance increases, one would expect transport costs to increase, thereby reducing trade between the countries. The remaining terms are dummy variables. $lang_{ni}$ is one when countries n and i speak a common language. One would expect lower trade costs between two countries that speak the same language. $colony_{ni}$ is one if countries n and i have or had a colonial relationship. Colonial relationships often result in reduced tariffs, common cultures, and pre-existing trading relationships so one would expect a positive relationship with trade. $border_{ni}$ is one when countries n and i share a common border. Similar to the distance variable, neighboring countries should have lower trade costs and conduct more trade.

Combining, I estimated trade costs using the following gravity model:

$$t_{ni} = \beta_0 + \beta_{dist}\log(dist_{ni}) + \beta_{lang}lang_{ni} + \beta_{border}border_{ni} + \beta_{colony}colony_{ni} + I_n + E_i + u_{ni} \qquad (14)$$

where u_{ni} is an iid error term. Table 2 presents the results:

Table 2: Gravity Results (1960-1990)

Variable	OLS
Constant	12.295
	0.317
Distance	-1.003
	0.036
Common Language	0.424
	0.085
Border	0.281
	0.146
Colony	0.631
	0.143
Observations	2,251
R^2	0.85

*Importer/ exporter fixed effects

All coefficients are consistent with the large literature on estimating gravity equations: trade is increasing in language, common borders, and colonial relationship, but decreasing in the distance between countries. Further, all coefficients are significant. I use these estimation results and equation 14 to calculate $\{\tau_{ni}\}$.

5.3 Entry Rate and Costs

The firm entry conditions, equation 7, are a function of entry rates and entry costs: an over-identified system of equations. Solving this system requires first pinning down either entry rates or entry costs. Rather than assume all countries have equal entry costs (f_i^e), I use data on country firm entry rates gathered in the World Bank Entrepreneurship Survey. The entry data is based on the average number of registered entering firms during years 2000 through 2007. By using this data, I assume that a) firm entry rates between countries are not materially different than for 1960-1990, b) entry into the informal sector is small and can be ignored, and c) entry is invariant to a country's IPR policy.

5.4 Other Parameters

There remaining parameters are $\{\epsilon, \eta, \beta, \delta\}$. I set ϵ to 6.8, the mean value for SITC three-digit goods during the period of 1972-1988 as described in Broda and Weinstein (2006). I set the share parameter for the differentiated goods (η) to 0.13 using the value identified computed by Eaton and Kortum (2002). The time discount factor β is 0.945 given a 7% return on US bonds. The firm death hazard is 10% in line with Bartelsman, Haltiwanger, and Scarpetta (2008).

The curvature parameter b is the lone remaining parameter. For simplicity, I assume that b is equal to one-half. The choice of b has little effect on the cross-section of IPR choices, though it does effect equilibrium

IPR levels. I present equilibrium IPR choices for alternate values of b in the appendix.

6 Solving the Model

As noted by numerous authors, solving the problem in Section 4 is computationally intensive (or impossible) for even moderately sized state spaces. This is referred to as the *curse of dimensionality* in the IO literature since the aggregate state space is exponentially increasing in the number of agents and possible agent states. I remedy the *curse of dimensionality* by approximating the open economy Markov-perfect equilibrium using the technique developed by Weintraub, Benkard, and Van Roy (2008). They show that when the set of agents (e.g., firms) is sufficiently large such that individual firms have little effect on the aggregate state, then solving a model where decisions are based on the long-run expected firm distribution closely approximates the MPE. Yu (2008) uses this approximation technique to estimate the R&D investment in the Korean electric motor industry.

I use this approximation technique to solve the model. Monopolistic competition implies by construction that firms make decisions taking the aggregate state and related laws of motion as given. Assuming that governments make their IPR decisions taking the aggregate state as given is a stronger assumption. In the model, trade is the only thing that connects countries, and trade costs limit these effects. As many studies have noted, these trade costs have a dramatic impact. Table 3 presents trade as a share of manufacturing spending[21]

[21] Spending on manufacturing goods is computed as each country's gross manufacturing production less manufacturing exports plus manufacturing imports.

Table 3: Manufacturing Import Share (1990)

Country	Imports as % of Mfg Spending	Imports from Sample as % of Mfg Spending
CAN	0.28	0.26
CHL	0.20	0.17
DEU	0.22	0.10
ESP	0.19	0.13
FIN	0.23	0.13
FRA	0.28	0.16
GBR	0.33	0.19
IND	0.06	0.03
JPN	0.04	0.03
KOR	0.16	0.13
MEX	0.34	0.32
USA	0.12	0.09
Avg	0.19	0.14

*Argentina, Brazil, and China are excluded due to data issues.

Imports account for, on average, 19% of a country's spending on manufactures overall and 14% of manufacture spending in the sample above. Canada and Mexico have relatively high import shares within the sample since both trade relatively more with the US. In general, these small import shares suggest that changes in IPR policy in one country, and ultimately changes in its firm productivity distribution, will have small effects on the other countries. That said, allowing governments to internalize the aggregate implications of their IPR policy choices would likely have some effect on the results presented below and is an interesting avenue for further research.

6.1 Approximating the Distribution of Firms (μ)

Solving the model without commitment adds an additional complication. Namely, I have to solve for optimal IPR decisions on and off the equilibrium path, which necessitates keeping track of the high-dimensional object μ. I address this issue by following Krusell and Smith (1998) and approximating μ with a finite set of moments. I use simulation to update the law of motion (Υ_i) and the government policy function (Ψ_i). The model lends itself well to this strategy since firms and governments make decisions based on the following two moments:

1. Price Index:

   The price index for country i (P_i) summarizes market competitiveness and μ naturally collapses into

P_i via

$$\begin{aligned} P_i(\mu) &= \left[\sum_{n=1}^{N} \sum_{x \in X} p_{in}(x; \tau_{in})^{1-\epsilon} \mu_n(x) \right]^{\frac{1}{1-\epsilon}}, \text{ where} \\ p_{in}(x; \tau_{in}) &= \frac{\tau_{in}}{\alpha \cdot x} \end{aligned}$$

2. Average Productivity:

   The average productivity $\overline{\mu}_i$ does two things. First, it provides information regarding the value of the technological spillovers in country i since the spillovers are a function of $\{\overline{\mu}_n\}_n$ where the approximation technique discussed above allows me to fix $\overline{\mu}_{-i}$. Secondly, it provides information about average firm productivity in the country, which helps identify government IPR decisions.

For a country i, the moments $(P_i, \overline{\mu}_i)$ provide sufficient information for firms and governments to make optimal decisions. As noted in Section 2, government IPR choices have been stable over the sample period. I use this as evidence to the existence of a steady-state.

Solving the model, then follows these steps:

1. Guess a value for the long-run expected firm productivity distribution. Call this $\tilde{\mu}^0 = [\tilde{\mu}_1^0, ..., \tilde{\mu}_N^0]$.

2. For each country i:

   - Solve for equilibrium IPR and firm decision rules using data on education, population, and the estimated τ_{ni}. Specific details of the computational algorithm are in the appendix.

     - Each country takes $\tilde{\mu}^0$ as given

     - The state for each government is $(P_i, \overline{\mu}_i)$

   - Given the equilibrium laws of motion, compute steady-state $\{\gamma_i^*, \overline{\mu}_i^*, P_i^*\}$

3. Given steady-states, compute $\tilde{\mu}^1$

4. Stop if $\| \tilde{\mu}^1 - \tilde{\mu}^0 \|_\infty$ is sufficiently small. Otherwise, set $\tilde{\mu}^0 = \tilde{\mu}^1$ and return to (2)

7 Results

While the Ginarte-Park index does provide a simple and effective way of mapping the abstract notion of IPR protection into a numerical index, replicating these numerical values is not meaningful. For example, if two countries have GP scores of 2 and 1, respectively, does the first country have a level of protection twice as strong as the first? Is the relationship exponential? Instead of attempting to match the specific values of the GP index, I evaluate my model using the Spearman rank-order correlation (ρ), which measures the ability of my model to replicate the ordinal ranking of countries observed in the data.

7.1 Benchmark Results

Table 4 presents the equilibrium IPR policies chosen by each country under the benchmark "no commitment" model, as well as the equilibrium IPR policies when I impose "commitment."

Table 4: Model Results

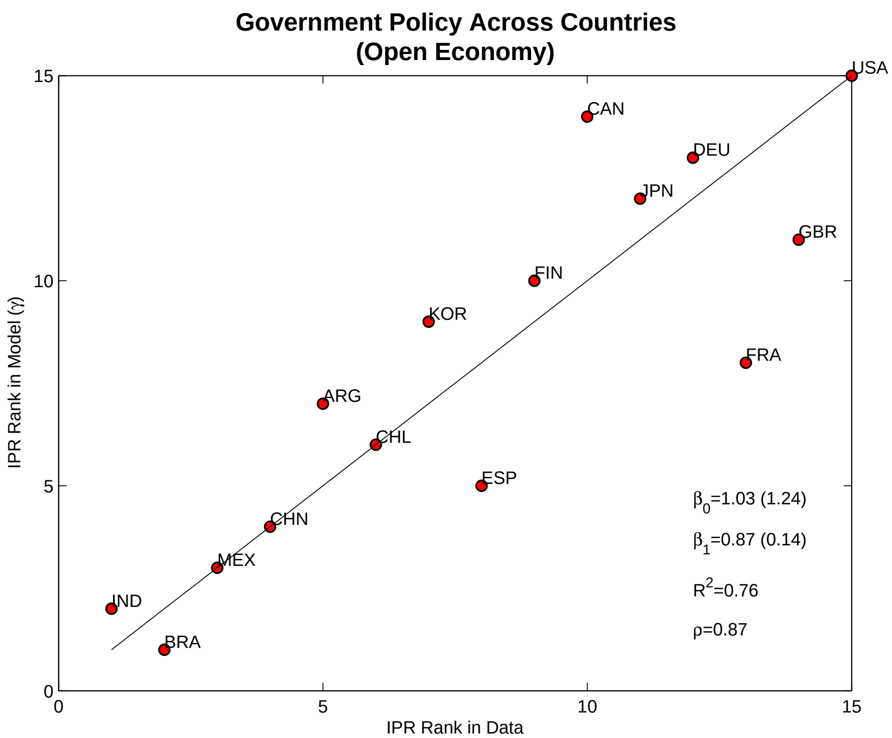
Country	No Commitment	Commitment	%Δ
IPR Policy (γ):			
USA	0.89	0.57	-35.7
GBR	0.85	0.41	-51.2
FRA	0.77	0.33	-57.6
DEU	0.86	0.43	-49.5
JPN	0.86	0.42	-51.1
CAN	0.88	0.52	-40.9
FIN	0.82	0.40	-50.9
ESP	0.68	0.20	-71.1
KOR	0.81	0.39	-52.4
CHL	0.74	0.27	-64.2
ARG	0.77	0.31	-60.0
CHN	0.61	0.12	-79.7
MEX	0.59	0.15	-75.1
BRA	0.37	0.10	-73.0
IND	0.47	0.10	-78.6
Summary Statistics:			
mean (γ)	0.73	0.31	-57.0
std (γ)	0.16	0.15	-2.9
R^2	0.76	0.76	0.0
Rank-Order Statistics:			
Correlation (ρ)	0.87	0.87	0.0
P-value (%)	0.002	0.002	0.0

*Countries in descending order according to Ginarte-Park Index.

Using the Spearman rank-order correlation (ρ) as an measure for goodness of fit, the benchmark model replicates the data well. The correlation is high (87%) and I can reject the null hypothesis that the model's results are uncorrelated with the data. Developed, research-intensive countries such as the US, Germany, and Japan choose the highest levels of protection, while developing, imitative countries like India, Brazil, and China choose low levels of protection. Also consistent with the data, countries are very heterogeneous in their protection choices.

Table 4 also compares the benchmark no commitment model with a model where I impose government commitment. Imposing government commitment has no effect on the model's fit, though equilibrium protection choices decrease 45.1%, on average. The intuition behind this latter result is that imposing commitment amounts to constraining government IPR policy, hence governments cannot adjust IPR policy to optimally maximize the firm productivity distribution. In steady-state, this means that firms are, on aggregate, less productive and can gain more through the technological spillovers. The steady-state government IPR policy with commitment is therefore lower.

The figure below compares the ordinal ranking implied by the benchmark model with the ordinal ranking observed in the data. The x-axis represents the observed ordinal ranking in the data from weakest IPR protection to greatest. (i.e, the US is right-most country), while the ordinal ranking predicted by the model is on the y-axis. If the model generates the ordinal ranking perfectly, all points would lie on the 45-degree line.



While the overall fit of the model is strong (as evidence by the high rank-order correlation), the model does a better job at replicating IPR choices amongst developing countries. Since countries in the model are heterogeneous only in their level of education, population (market size), and bilateral trade costs, this result indicates that additional factors drive developed country IPR decisions. For example, while I choose parameters based broadly on observed trade for all manufacturing goods, developed countries may concentrate production and trade within specific manufacturing sub-sectors. The research intensity and IPR sensitivity of these sub-sectors would likely impact the IPR choices of the country.

7.2 Effect of Trade on Policy Choices

As mentioned earlier, trade introduces two effects into the economy. First, it introduces export markets, which increases the market size for all firms, thereby increasing expected discounted profits and optimal firm R&D. This results in more productive firms and, therefore, an increase in the level of IPR chosen by the government. Call this the "market effect". Trade also allows firms in one country to learn from firms in other countries leading to increased technological spillovers. The increase in technological spillovers results in a decrease in the level of IPR chosen by the government. Call this the "learning effect." The market and learning effects are countervailing forces.

Table 5 presents the equilibrium IPR decisions and welfare effects in a world without trade.

Table 5: Closing the Economy

	Protection Choices (γ)			Welfare (%Δ)	
Country	Open	Closed	%Δ	IPR Fixed	IPR Flexible
USA	0.89	0.90	0.4	-1.4	-0.8
GBR	0.85	0.80	-6.0	-4.5	-2.0
FRA	0.77	0.78	0.2	-1.7	-1.1
DEU	0.86	0.87	0.5	-1.0	-0.8
JPN	0.86	0.86	0.3	-0.8	-0.5
CAN	0.88	0.87	-0.6	-2.1	-0.9
FIN	0.82	0.83	0.4	-1.4	-0.7
ESP	0.68	0.65	-4.4	-2.3	-1.3
KOR	0.81	0.79	-2.7	-3.4	-1.3
CHL	0.74	0.74	-0.0	-1.7	-1.0
ARG	0.77	0.77	0.2	-0.4	-0.6
CHN	0.61	0.62	0.7	-1.2	-0.6
MEX	0.59	0.49	-16.7	-1.4	-0.8
BRA	0.37	0.37	-0.8	-1.5	-0.8
IND	0.47	0.47	-0.0	-0.1	-0.3
mean	0.73	0.72	-1.9	-1.7	-0.9
std	0.16	0.16	4.5	1.1	0.4
R^2	0.76	0.73	-4.1		
Correlation (ρ)	0.87	0.85	-2.0		
P-value (%)	0.00	0.01	0.0		

*Countries in descending order according to Ginarte-Park Index.

Reducing the world to autarky has several implications. First, countries choose, on average, a level of IPR protection 2% lower than the benchmark model. This indicates that the market effect dominates the learning effect in all of the countries. Second, closing the economy to trade has significant welfare implications. The "IPR Fixed" column presents welfare effects when countries are constrained to the benchmark model choice of IPR protection. Country welfare decreases 1.7%, on average, in this scenario. The "IPR Flexible" column presents the welfare effects when countries are allowed to choose a different level of protection.[22] Under this scenario, countries are better off as average welfare decreases only 0.9%.

8 Counterfactual Exercises

Since the model does a good job of replicating protection choices in the data, I'll now use it to quantify the welfare effects of two counterfactual experiments. Welfare in country i is measured by real income Y_i/P_i^{η}[23]. Since both labor L_i and wages are fixed, income Y_i is fixed with respect to the numeraire. Consequently, welfare gains and losses are captured by changes in the price index. Specific details regarding computation of these counterfactuals are located in the appendix.

8.1 Exercise 1: All Countries Move to US Standard

In this counterfactual, all countries exogenously adopt US protection standards and these standards are constant for all periods ($\Psi_i(\mu) = \gamma_{\text{usa}}, \quad \forall i = 1, ..., N$). It is important to note that I assume the WTO imposes this adoption and can enforce compliance (i.e., there exists a commitment technology in the the future steady-state). Table 6 presents the welfare results by country.

[22] As with the benchmark model, countries do not commit to their IPR choice.

[23] Recall the homogeneous good is numeraire and therefore has normalized price of one.

Table 6: Harmonization to US Standards

Country	Welfare Change (%Δ)
USA	0.01
GBR	0.01
FRA	-0.00
DEU	0.00
JPN	-0.00
CAN	-0.02
FIN	-0.00
ESP	-0.00
KOR	-0.02
CHL	-0.00
ARG	0.01
CHN	-0.04
MEX	-0.07
BRA	-0.03
IND	-0.05
mean	-0.01
std	0.02
γ	0.89

*Countries in descending order according to Ginarte-Park Index.

Ex ante, harmonizing protection to US standards is a non-trivial exercise when the economies are integrated through trade. Take the US for example. Higher protection overseas increases firm profits abroad as foreign firms fail to catch-up. The increased profits can lead to more innovation and firm entry. Both of these effects increase US welfare. Decreased foreign firm productivity, however, can also negatively impact US welfare, since decreased productivity leads to less foreign goods available in the US.

The model indicates that increasing protection to US standards has mixed effects amongst the country sample. Developed countries tend to experience welfare increases, though these effects are small. Welfare in developing countries largely decreases, though again not substantially.

8.2 Exercise 2: Global Standard

Now, I assume a planner (or the WTO) chooses and commits to a harmonized IPR policy for all countries.[24] The planner chooses this IPR policy by solving the following maximization problem:

$$
\begin{aligned}
W(\mu) &= \sum_{n=1}^{N} U_n(\mu) + \max_{\gamma} \beta W(\mu') \\
\text{s.t.} & \\
\mu' &= \Upsilon(\mu, \gamma) \\
L_i &= L_i^M + e_i f_i^e + \sum_{x \in X} \left[l_i(x) + \iota_i(x) \right] \mu_i(x) \;\; \forall i
\end{aligned}
$$

where γ is single-valued (i.e., all countries have the same IPR) and the resource. Commitment implies future policy choices are constrained by this choice $\gamma'' = \Psi(\mu) = \gamma'$. Table 7 presents the welfare results by country.

Table 7: Harmonization to Global Standard

Country	Welfare Change (%Δ)
USA	0.01
GBR	0.00
FRA	-0.00
DEU	0.00
JPN	-0.00
CAN	-0.03
FIN	-0.01
ESP	0.00
KOR	-0.03
CHL	0.00
ARG	0.01
CHN	-0.03
MEX	-0.06
BRA	-0.01
IND	-0.05
mean	-0.01
std	0.02
γ	0.49

*Countries in descending order according to Ginarte-Park Index.

The optimal global policy is significantly lower (higher) than the levels established by most of the developed (developing) countries in the benchmark model. When countries create IPR policy independently, the average protection choice was $\gamma = 0.73$. The optimal global standard is significantly lower than this figure ($\gamma^* = 0.49$)

[24] This exercise does not represent a specific evaluation of the TRIPS agreement for two reasons. First, TRIPS was one component (albeit an important one) of a larger set of trade negotiations. As such, TRIPS likely reflects concerns regarding IPR protection as well as negotiated tariffs. Secondly, TRIPS designated a minimum level of protection, while here I evaluate the socially optimal level of protection where all countries are subject to the same level of protection.

The average welfare effect is positive but small and not all countries are better off with a global standard - developing countries are largely worse off, while developed countries largely better off. The United States, Great Britain, and Germany all experience welfare increases under the global standard. Welfare in China, Mexico, Brazil, and India all decrease. Under the planner's IPR choice, developing countries are forced to adhere to a higher level of IPR. This limits developing country firms from catching up with the rest of the world. This decrease in competitiveness, leads to an increase in export markets and expected discounted profits for developed country firms. These firms can then invest more money in R&D, becoming more productive. Increased export markets can also lead to an increase in firm entry rates, though this doesn't appear quantitatively important in the model.

The fact that harmonization in both policy experiments resulted in developed countries becoming better off seems to support the results of McCalman (2005), who estimates a significant increase in royalty payments to developed countries as a result of TRIPS implementation.

9 Conclusion

Papers like Helpman (1993) and Grossman and Lai (2004) provide qualitative insight into why countries choose different levels of protection, as well as the potential welfare effects of IPR harmonization. This paper extends their work into a multi-country dynamic game in which IPR protection is endogenous. I use country heterogeneity in education, population, and bilateral trade costs to induce equilibrium IPR decisions consistent with the data.

I use the benchmark model to evaluate the effects of trade and government commitment. I find that trade has little impact on the rank-order of country IPR decisions, though reducing the world to autarky does reduce equilibrium IPR decisions by 2%, on average. Imposing government commitment, on the other hand, decreases average IPR protection substantially.

I also quantify the welfare effects of global harmonization to a single IPR standard. First, I examine a world where all countries adopt US standards and the WTO enforces commitment. I find that average country welfare decreases, though most developed countries are better off. Second, I solve a planner's problem where the planner (or the WTO) chooses a single IPR standard for all countries. I find that average welfare decreases, though not substantially. Developed countries are largely better off, while developing countries are largely worse off.

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A Appendix

About Intellectual Property Rights

The paper largely deals with utility patents[25]. Utility patents largely grant the holder

> the right to exclude others from making, using, offering for sale, or selling the invention... or importing... products made by that process (USPTO)

In exchange, the inventor makes his/ her invention public information. The state hopes this revelation enables others to learn from the invention, enhancing their own inventiveness, and leading to more productive innovations for the country at large. This revelation is actually quite a commitment since any patent application must

> disclose the invention in a manner sufficiently clear and complete for the invention to be carried out by a person skilled in the art [26] (TRIPS)

The cost of this trade-off is particularly stark in the U.S. where patent applications become public information 180 days after submission.[27] Consequently, the firm may reveal its idea before even taking advantage of the idea itself, thereby enabling competitors to piggy-back on its R&D efforts.

The confluence of an ever-tightening global economy and increasing respect of IPRs have led to a sharp increase in patent applications over the last 15 years. From 1975 until 1992, global patent applications increased YOY at a rate of 7.2%. From 1992 until 2002, this statistic increased to 21.8%. Hidden below this increase are two interesting data trends. First, the driver of growth has not only been on the internal margin (countries patenting more in countries they already patented in) but also on the external margin (countries patenting in countries they haven't patented in before).

New international treaties on IPR protection are partly responsible. The increasing effects of globalization and cross-country differences in intellectual property rights (IPRs) have become a heated issue. An oft cited statistic contends that US corporations lost an estimated $23.8 billion in 1986 from foreign patent infringement (USITC). While the exact magnitude of this figure is clearly biased, anecdotal evidence ranging from

[25] For example other forms of intellectual property right protection are copyrights and trademarks.

[26] It's important to note that TRIPS is mute on differences in cross-country differences in the level of skill in any particular "art". Presumably, one would only need to show that a person skilled in the art in any country, not necessarily the one in question, could replicate the invention.

[27] The combination of a sharp increase in number, breadth, and complexity of patent applications, has inundated the USPTO. In response, it uses the input of the outside world to help verify the validity of patent claims. Ironically, the patent office is using the strategy of open-source software development to aid in its efforts.

pirated versions of Microsoft Windows in China to imitated pharmaceuticals in Brazil suggest the magnitude of foreign patent infringement is quite high.

Developed countries sought to reduce the hazard of imitation through the WTO-sponsored Uruguay Trade round. One component of the trade round, the Trade-Related aspects of Intellectual Property rights (TRIPS) treaty, mandated a non-trivial level of minimum patent standards.[28] Specifically, TRIPS defines how a country should provide adequate protection within its borders, requires all patent rights be granted (enforced) agnostic of the applicant's (holder's) residency, and outlines how to handle infringement claims between WTO members. Further, TRIPS' incorporation with the WTO suggests a real bite should a country be found in violation.

The second, and perhaps more interesting, trend is that patent application flows are asymmetric across countries. That is, the set of countries in which US firms file patent applications is quite different than the set of countries which have firms filing for patents in the US. For example, U.S. firms filed for patents in 60 countries in 2000, compared to 36 countries filing for patents in the United States. Further, these differences appear relatively persistent across time.[29] The persistence of these differences suggest some very structural issues driving patenting decisions, while the asymmetry of these flows across countries suggests the form of these structural differences is country-pair specific (e.g., US-Mexico, Japan-Germany, etc.).

[28] TRIPS actually defines legal standards for copyrights, trademarks, genetic sequencing, industrial designs, and integrated circuits layout designs, as well as patents.

[29] As noted earlier, the data does indicate an increase in the breadth of countries being patented in.

Ginarte-Park IPR Index

Table 8: Breaking Down the Ginarte-Park IPR Index

Category / Criteria		
(1) Coverage (COV)	Available	Not Available
Patentability of pharmaceuticals	1/7	0
Patentability of chemicals	1/7	0
Patentability of food	1/7	0
Patentability of plant and animal varieties	1/7	0
Patentability of surgical products	1/7	0
Patentability of microorganisms	1/7	0
Patentability of utility models	1/7	0
(2) Duration of Protection (DUR)	Full	Partial or No Protection
where full duration is 20 years from the date of application (or 17 years from the date of grant, for grant-based patent systems) and f equals the duration of protection as a fraction of the full duration.	1	$0 < f < 1$
(3) Enforcement (ENF)	Available	Not Available
Preliminary Injunctions	1/3	0
Contributory Infringement	1/3	0
Burden-of-Proof Reversal	1/3	0
(4) Membership in International Treaties (MEM)	Available	Not Available
Paris Convention and Revisions	1/3	0
Patent Cooperation Treaty	1/3	0
Protection of New Varieties (UPOV)	1/3	0
(5) Restrictions on Patent Rights (RIG)	Does Not Exist	Exists
Working Requirements	1/3	0
Compulsory Licensing	1/3	0
Revocation of Patents	1/3	0
Total Points Possible	5	-

Data Sources

Variable	Description	Source
T_{ni}	Bilateral trade flows	Feenstra, Lipsey, Deng, Ma, and Mo (2005)
IPR_n	Patent regime strength	Ginarte and Park (1997)
educ_n	Human capital (avg yrs of education)	Barro and Lee (2000)
dist_{ni}	Distance (capitals)	Helpman, Melitz, and Rubinstein (2008)
lang_{ni}	Common language dummy	Helpman, Melitz, and Rubinstein (2008)
colony_{ni}	Colonial heritage dummy	Helpman, Melitz, and Rubinstein (2008)
border_{ni}	Common borer dummy	Helpman, Melitz, and Rubinstein (2008)
L_n	Population	Penn World Table 6.2 (2008)
Entry_n	Firm entry rates	World Bank Group (2008)

A special thanks to Walter Park for sharing the updated IPR scores. The education data is based on average years of education completed for individuals greater than 25 years of age.

Proofs

Proposition 1 *Given assumption (**??**), firm entry follows a Poisson random variable. Moreover, there exists a cut-off mass of entering firms (e) such that* $\frac{1}{1+r} \cdot E[V(x', \mu')|F^e, e] = f^e$.

Proof

I first show that entry follows a Poisson random variable. The proof follows Weintraub, Benkard, and Van Roy (2008). There are F potential entrants where F is assumed sufficiently large and each firm enters with the same probability p_F. Define $V_F(f)$ as the expected discounted profit flows for each entering firm if f firms enter simultaneously. By construction, $V_F(f)$ is decreasing in f. Free entry then implies the following equation must hold

$$\sum_{f=0}^{F-1} p_F^f (1-p_F)^{F-f-1} V_F(f+1) - f^e = 0 \tag{15}$$

for which there exists a unique solution $p_F^* \in (0,1)$ for each sufficiently large F, where assumption (**??**) guarantees an interior solution. Further, define $e = \lim_{F\to\infty} F p_F^*$ and X_F as a binomial random variable with parameters (F, p_F^*). Then $\lim_{F\to\infty} X_F = Z$ where Z is a Poisson random variable with parameter e.

So long as the number of potential entrants is sufficiently large and each potential entrant plays the same mixed entry strategy, then entry can be modeled as a Poisson random variable with expected entry e. ■

Proposition 2 *The incumbent firm value function exists, is unique, continuous, strictly increasing, and differentiable.*

Proof

Fact 1: Firm productivity exists in the discrete set X, which is by assumption a Borel set on $\mathbb{R}$.

Fact 2: Assume that incumbent firm R&D (ι) is continuous in x. Recall that the transition function F in country i is defined as

$$F(x'|x, \iota \cdot R_i) = \begin{cases} \frac{R_i \cdot \iota}{1+R_i \cdot \iota} & x' = x^{k+1} \\ \frac{1}{1+R_i \cdot \iota} & x' = x^{k-1} \end{cases}$$

which is clearly continuous in ι. Then for any bounded continuous function f, the operator T defined as

$$Tf(x) = \sum_{s' \in X} f(s')F(s'|x, R_i, \iota)$$

is continuous in x. Therefore, F has the Feller property.

Fact 3: Firm R&D (ι) is clearly non-empty, compact-valued, and continuous.

Fact 4: Recall that profits for a firm from country i is

$$\begin{aligned} \pi_i(x, \mu) &= \sum_n \pi_{ni}(x, P_n(\mu)) \\ &= \sum_n x^{\epsilon-1} \left[\frac{\tau_{ni}\alpha}{P_n(\mu)} \right]^{1-\epsilon} (1-\alpha)\eta Y_n \end{aligned}$$

Firm profits are clearly bounded on X and $\frac{1}{1+r} \in (0, 1)$ by assumption. Then by Stokey and Lucas (1989) Theorem 9.6, Facts 1-4 imply the incumbent firm value function exists and is unique.

Fact 5: Firm R&D (ι) is strictly increasing in x.

Fact 6: Profits are strictly increasing in x.

Then by Stokey and Lucas (1989) Theorem 9.7, Facts 1-6 imply the incumbent firm value function is strictly increasing. Continuity and differentiability follows accordingly. ■

Proposition 3 *(Existence) There exists an equilibrium to the to the OEMPE.*

Proof

Given government protection choice Ψ, the problem collapses to a MPE similar to Doraszelski and Satterthwaite (2007).

Fact 7: The productivity transition function F is *unique investment choice (UIC)* admissible.[30]

Then by Doraszelski and Satterthwaite (2007) Proposition 2 and Facts 1-7, an equilibrium exists. Now step back and look at the problem for welfare-maximizing governments. Define the function f as the best response function with domain $[0, 1]^N$ and range $[0, 1]^N$.

Lemma 1 *The function f is continuous.*

Proof

Without loss of generality, look at the problem for country n and consider an ϵ change in protection choices for the other countries. Firm investment decisions are clearly continuous in the protection level, hence the distributions are also continuous. The ϵ change, therefore leads to a continuous change in average productivity for country n. Consequently, country n's protection policy changes continuously. ■

So I have a continuous function f on a closed unit ball. By Brouwer's Fixed Point Theorem, there exists at least one fixed point. ■

Robustness

The results associated with the benchmark no commitment model are based on a specific value for the curvature parameter b (0.5). I contend that the overall performance of the model is quite robust to this choice. Table 9 presents equilibrium policy choices conditional on different values for b.[31]

[30] See Doraszelski and Satterthwaite (2007).

[31] The table compares results assuming government commitment, which is substantially faster to compute.

Table 9: Country Protection Choices (γ) with Different Values for b

Country	b=0.5	b=0.25	b=0.75	b=1.0
USA	0.57	0.62	0.57	0.61
GBR	0.41	0.55	0.41	0.22
FRA	0.33	0.51	0.33	0.01
DEU	0.43	0.56	0.43	0.28
JPN	0.42	0.55	0.42	0.24
CAN	0.52	0.59	0.52	0.48
FIN	0.40	0.54	0.40	0.20
ESP	0.20	0.45	0.34	0.01
KOR	0.39	0.54	0.39	0.01
CHL	0.27	0.49	0.27	0.01
ARG	0.31	0.50	0.31	0.01
CHN	0.12	0.40	0.12	0.01
MEX	0.15	0.41	0.15	0.01
BRA	0.37	0.33	0.10	0.01
IND	0.47	0.32	0.10	0.01
Summary Statistics:				
Correlation (ρ)	0.87	0.87	0.87	0.45
R^2	0.76	0.76	0.76	0.50

*Gray column indicates benchmark model with commitment

All four models generate reasonably high R^2 statistics and rank-order correlations. When b=1, the government objective function is not necessarily strictly concave. This increases the possibility of corner solutions as exhibited by the large number of countries choosing near zero protection (γ close to zero). Since no country chooses perfect or no protection in the sample and empirical evidence indicates some complementarity between the innovative and spillover technologies, I reject this model. The other models demonstrate that changing b has some impact on the IPR levels, but does not effect the rank-ordering of IPR decisions.

Computational Algorithm

In this section, I outline the computational algorithm used to solve for the equilibrium. The algorithm used is similar in methodology to Corbae, D'Erasmo, and Kuruscu (2009). I begin with some introductory remarks and then proceed to outline the algorithm more systematically. For simplicity, the algorithm outlined is only for the closed economy model. Extending it to an open economy model, amounts to adding an external loop for trade. The loop terminates when policy, trade, and innovation decisions and the set of world productivity distributions are consistent.

A.0.1 Approximating μ

Recall that the distribution of firms affects individual firm decisions through competition (via the price index) and technological spillovers. Recall the mapping between the technological spillover (S) and μ is

$$S_i(x,\mu) = \frac{\sum_{n=1}^{N} \omega_{in} \overline{\mu}_n}{x}$$

I approximate the infinite-dimensional distribution μ_n with the price index P_n and the average productivity $\overline{\mu}_n$, where $(P_n, \overline{\mu}_n)$ are defined by

$$\begin{aligned} P_n(\mu) &= \left[\sum_{i=1}^{N} \sum_{x \in X} p_{ni}(x)^{1-\epsilon} \mu_i(x)\right]^{\frac{1}{1-\epsilon}} \\ \overline{\mu}_n &= \frac{\sum_{x \in X} x \mu_n(x)}{\sum_{x \in X} \mu_n(x)} \end{aligned}$$

For ease of exposition, consider the closed-economy model where

$$\omega_{in} = \begin{cases} 1, & \text{if } i = n \\ \\ 0, & \text{if } i \neq n \end{cases}$$

The incumbent firm's problem is then

$$V(x,P,\overline{\mu}) = \pi(x,P) + \max_{\iota} \begin{Bmatrix} -\iota \\ + \frac{1}{1+r} E_{F(x'|x,\iota \cdot R)} V(x', P', \overline{\mu}') \end{Bmatrix} \tag{16}$$

s.t.

$$\begin{aligned} \pi(x,P) &= x^{\epsilon-1} \cdot (1-\alpha) \left[\alpha P\right]^{\epsilon-1} \eta Y \\ R &= \left[\mathrm{H}\gamma^b + S(x,\overline{\mu}) \cdot (1-\gamma)^b\right]^{1/b}, \quad b \in (0,1] \\ \gamma &= \Psi(P, \overline{\mu}) \\ \overline{\mu}' &= \Upsilon_{\overline{\mu}}(P, \overline{\mu}, \gamma) \\ P' &= \Upsilon_P(P, \overline{\mu}, \gamma) \end{aligned}$$

where the functions $\Upsilon_{\overline{\mu}}$ and Υ_P are the laws of motion for average productivity and the price index, respectively. Given state $(P, \overline{\mu})$, the mass of entering firms is

$$\begin{aligned} e(P,\overline{\mu}) : \frac{1}{1+r} \cdot E[V(x', P', \overline{\mu}')|G] &= f^e \quad (17) \\ \text{s.t.} \qquad \gamma &= \Psi(P, \overline{\mu}) \\ \overline{\mu}' &= \Upsilon_{\overline{\mu}}(P, \overline{\mu}, \gamma) \\ P' &= \Upsilon_P(P, \overline{\mu}, \gamma) \end{aligned}$$

The government value function becomes

$$\begin{aligned} W(P,\overline{\mu}) &= \max_{\gamma} \{U(P) + \beta W(P', \overline{\mu}')\} \quad (18) \\ \text{s.t.} \qquad \gamma &= \Psi(P, \overline{\mu}) \\ \overline{\mu}' &= \Upsilon_{\overline{\mu}}(P, \overline{\mu}, \gamma) \\ P' &= \Upsilon_P(P, \overline{\mu}, \gamma) \end{aligned}$$

with one-shot deviation

$$\begin{aligned} \tilde{W}(P,\overline{\mu},\gamma) &= \max_{\gamma'} \{U(P) + \beta W(P')\} \quad (19) \\ \text{s.t.} \qquad \overline{\mu}' &= \Upsilon_{\overline{\mu}}(P, \overline{\mu}, \gamma') \\ P' &= \Upsilon_P(P, \overline{\mu}, \gamma') \end{aligned}$$

Useful Operators

Note that the distribution μ is a measure on $(\mathbb{R}, \mathcal{B})$ where B is a Borel σ-algebra. Let $\mathcal{P}(\mathbb{R})$ be the space of probability measures on $(\mathbb{R}, \mathcal{B})$ and define the operator $\Phi : \mathcal{P}(\mathbb{R}) \to \mathcal{P}(\mathbb{R})$ as

$$(\Phi\mu)(x') = \delta \sum_{x \in X} F(x'|x, \iota \cdot R)\mu(x) + G(x')e \quad (20)$$

While I've suppressed their arguments, it is important to remember that ι is dependent upon the government policy (γ). This operator will be important when computing transitions between states, updating the laws of motion $(\Upsilon_P, \Upsilon_{\overline{\mu}})$, and solving for the equilibrium.

Note that one can fix γ and use Φ to create a stationary distribution μ^{SS} as in the Oblivious Equilibrium concept developed by Weintraub, Benkard, and Van Roy (2008). I use these steady-state distributions to search for the steady state equilibria, since they should be contained in a local neighborhood of the OE solutions.

The Algorithm

The following algorithm is for the closed economy "no commitment" model. Extending the algorithm to the open-economy model requires a further contraction on the set of country distributions $\{\mu_n\}$. As before, I suppress all country subscripts to simplify the notation.

1. Let $\Psi^n(P, \overline{\mu})$ be government policy function for iteration n, where I use the identity function when n=1

2. Given $\Psi^n(P, \overline{\mu})$, solve the OE. Let $\Upsilon^s_P(P, \overline{\mu}, \gamma)$ and $\Upsilon^s_{\overline{\mu}}(P, \overline{\mu}, \gamma)$ be the laws of motion for the price index and average spillover, respectively. I use the identity function for s=1. The following steps update Υ_P and $\Upsilon_{\overline{\mu}}$ such that firm behavior and the laws of motion are consistent.

   (a) Solve the incumbent firm's decision rule (**??**) $\forall x$

   (b) Simulate a data set by creating transition distributions beginning at each steady-state. For each $\gamma_j, j = 1, ..., J$ (call this $\gamma_{j,0}$)

      i. Solve for the OE steady-state distribution (call this $\mu^{j,0}$) for all countries and calculate $P^{j,0}, \overline{\mu}^{j,0}$.

      ii. Use $\Psi(P^{j,0}, \overline{\mu}^{j,0})$ to produce $\gamma^{j,1}$

      iii. Use $\Psi(P^{j,0}, \overline{\mu}^{j,0})$, and $\gamma^{j,1}$ to solve for optimal R&D investment (ι)

      iv. Use $(P^{j,0}, \overline{\mu}^{j,0}, \gamma^{j,1}, \iota, e)$ to generate $\mu^{j,1}$, where e is the mass of entering firms from the data. Use this distribution to solve for $P^{j,1}, \overline{\mu}^{j,1}$

      v. Define $\overline{J}$ s.t. $j = 1, ..., \overline{J}$ and
      $\{\gamma_{j,\overline{J}}, \mu_{j,\overline{J}}\} \in SS = \{\text{set of steady-state distributions}\}$

   (c) Combine the policy sequences (J) to create a single simulated data set $\{\gamma^j, \overline{\mu}^j, P^j\}_{j=1}^{Jx\overline{J}}$

   (d) Run OLS regressions (see below for assumed OLS structure) on the simulated data set to create Υ^{s+1}_P and $\Upsilon^{s+1}_{\overline{\mu}}$

   (e) If $\max\{\| \Upsilon^s_{\overline{\mu}} - \Upsilon^{s+1}_{\overline{\mu}} \|_\infty, \| \Upsilon^s_P - \Upsilon^{s+1}_P \|_\infty\}$ is small then move to the next step. If not, let $s = s+1$ and repeat (2).

3. Update the government policy function Ψ^n using the results from (2)

   (a) Start from the OE steady-states and calculate $(P^{j,0}, \overline{\mu}^{j,0}\}$ for each γ.

(b) For each γ' deviation, use the firm $V(\cdot)$ and government $W(\cdot)$ value functions from step 2 to construct the one-shot deviation value functions
$(\tilde{V}(x,P,S),\gamma'),\tilde{W}(P,\overline{\mu},\gamma')$.

(c) Solve for next period's distributions and protection rates $(P^{j,1},\overline{\mu}^{j,1},\gamma^{j,1})$

(d) Combine the policy sequences (J) to create a single simulated data set $\{\gamma^j,P^j,\overline{\mu}^j\}_{j=1}^{Jx\overline{J}}$

(e) Run OLS regression (see below for assumed OLS structure) on the simulated data set to create Ψ^{n+1}

(f) If $\| \Psi^n - \Psi^{n+1} \|_\infty$ is small then move to the next step. If not, let $n = n+1$ and go back to (2).

4. We now have solutions for $\Upsilon_{\overline{\mu}}$, Υ_P, and Ψ. The final step is to find the steady-state by solving the following set of linear equations

$$
\begin{aligned}
\overline{\mu}^* &= \Upsilon_{\overline{\mu}}(P^*,\overline{\mu}^*,\gamma^*) \\
P^* &= \Upsilon_P(P^*,\overline{\mu}^*,\gamma^*) \\
\gamma^* &= \Psi(P^*,\overline{\mu}^*,\gamma^*)
\end{aligned}
$$

Laws of Motion

I approximate the laws of motion for firm distribution and government policy, both on and off the equilibrium path, using structure similar to Krusell and Smith (1998) and Corbae, D'Erasmo, and Kuruscu (2009). Specifically, states evolve according to the following processes:

- Law of motion for government protection policy (Ψ)

$$\gamma' = a_0 + a_1 P + a_2 \overline{\mu} \tag{21}$$

- Law of motion for the price index (Υ_P)

$$P' = b_0 + b_1 P + b_2 \overline{\mu} + b_3 \gamma \tag{22}$$

- Law of motion for mean productivity (Υ_μ)

$$\overline{\mu}' = c_0 + c_1 P + c_2 \overline{\mu} + c_3 \gamma \tag{23}$$

The tables below summarize the equilibrium laws of motion for each country in the sample.

Table 10: Computed Laws of Motion - Ψ

Country	a_0	a_1	a_2
USA	1	-1.9	-0.01
	(0.0053)	(0.22)	(5.1e-05)
GBR	1.6	-4.2	-0.08
	(0.054)	(2)	(0.00062)
FRA	1.1	-3.7	-0.025
	(0.011)	(0.34)	(0.00014)
DEU	2.1	-19	-0.071
	(0.035)	(1)	(0.00029)
JPN	2.3	-22	-0.085
	(0.033)	(1)	(0.0003)
CAN	1	-1.8	-0.01
	(0.005)	(0.16)	(5.7e-05)
FIN	1.2	1.1	-0.049
	(0.044)	(0.86)	(0.00048)
ESP	1.2	-5.1	-0.043
	(0.013)	(0.38)	(0.00028)
KOR	1	3	-0.037
	(0.024)	(0.78)	(0.0003)
CHL	1.2	-3.6	-0.033
	(0.012)	(0.27)	(0.00017)
ARG	1.2	-2.6	-0.03
	(0.017)	(0.36)	(0.00016)
CHN	1	-4.1	-0.039
	(0.014)	(0.59)	(0.00026)
MEX	0.98	-4.8	-0.032
	(0.0086)	(0.27)	(0.00025)
BRA	0.86	-6.3	-0.039
	(0.0068)	(0.21)	(0.0002)
IND	0.7	4.6	-0.048
	(0.016)	(0.38)	(0.00021)

Table 11: Computed Laws of Motion - Υ

Country	Υ_P				$\Upsilon_{\overline{\mu}}$			
	b_0	b_1	b_2	b_3	c_0	c_1	c_2	c_3
USA	0.00042	0.98	1.2e-07	9.7e-07	4	-99	0.81	-0.018
	(1.4e-05)	(0.00059)	(1.6e-07)	(3.7e-07)	(0.11)	(4.4)	(0.0012)	(0.0028)
GBR	0.00023	0.99	8.7e-07	1.6e-06	5	-1.2e+02	0.8	-0.017
	(1.3e-05)	(0.00048)	(1.9e-07)	(4.4e-07)	(0.094)	(3.4)	(0.0013)	(0.0032)
FRA	0.00038	0.99	4.8e-07	2.3e-06	3.8	-64	0.8	-0.02
	(1.8e-05)	(0.00052)	(2.5e-07)	(6.9e-07)	(0.093)	(2.7)	(0.0013)	(0.0036)
DEU	0.00034	0.99	6.2e-07	1.3e-06	3.6	-56	0.8	-0.016
	(2.5e-05)	(0.0007)	(2.6e-07)	(6.2e-07)	(0.14)	(3.8)	(0.0014)	(0.0034)
JPN	0.00024	0.99	9.1e-07	1.5e-06	4.6	-88	0.8	-0.016
	(2e-05)	(0.00061)	(2.3e-07)	(5.5e-07)	(0.12)	(3.7)	(0.0014)	(0.0034)
CAN	0.00058	0.98	-3.4e-07	1.6e-06	3.7	-67	0.81	-0.019
	(1.7e-05)	(0.00053)	(2.2e-07)	(5.4e-07)	(0.088)	(2.7)	(0.0012)	(0.0028)
FIN	0.00051	0.99	1.1e-06	3.1e-06	4.4	-53	0.8	-0.018
	(2.8e-05)	(0.00055)	(3.6e-07)	(9.1e-07)	(0.1)	(2)	(0.0013)	(0.0033)
ESP	0.00045	0.99	2.1e-08	3.6e-06	3.6	-60	0.81	-0.024
	(1.4e-05)	(0.0004)	(3.3e-07)	(1e-06)	(0.062)	(1.8)	(0.0015)	(0.0044)
KOR	0.00027	0.99	1e-06	2.1e-06	4.9	-1.1e+02	0.8	-0.018
	(1.4e-05)	(0.00046)	(2.1e-07)	(5.2e-07)	(0.087)	(2.8)	(0.0013)	(0.0032)
CHL	0.00051	0.99	7.8e-07	3.4e-06	3.8	-48	0.8	-0.02
	(2.1e-05)	(0.00048)	(3.5e-07)	(1e-06)	(0.082)	(1.9)	(0.0014)	(0.0039)
ARG	0.00034	0.99	1.7e-06	1.9e-06	3.9	-48	0.8	-0.017
	(3.1e-05)	(0.00066)	(3.4e-07)	(9.2e-07)	(0.13)	(2.7)	(0.0014)	(0.0038)
CHN	0.00023	0.99	1.5e-06	2.2e-06	4.3	-1.1e+02	0.8	-0.014
	(1e-05)	(0.00042)	(2e-07)	(6.2e-07)	(0.071)	(3)	(0.0014)	(0.0044)
MEX	0.00049	0.98	-3.8e-06	3.2e-06	3.1	-56	0.82	-0.028
	(1.3e-05)	(0.00039)	(4.1e-07)	(1.4e-06)	(0.054)	(1.6)	(0.0017)	(0.0058)
BRA	0.0007	0.98	-1.3e-05	6.1e-06	1.3	-15	0.89	-0.058
	(1.2e-05)	(0.00037)	(3.7e-07)	(2.6e-06)	(0.037)	(1.1)	(0.0011)	(0.0078)
IND	8e-05	1	3.3e-06	-6.3e-08	5.7	-95	0.79	0.0076
	(1.9e-05)	(0.00046)	(2.6e-07)	(8.7e-07)	(0.09)	(2.2)	(0.0012)	(0.0041)

Table 12: Computed Laws of Motion - R^2

Country	Ψ	Υ_P	Υ_μ
USA	0.9484	0.9992	0.9964
GBR	0.8820	0.9995	0.9962
FRA	0.9323	0.9994	0.9956
DEU	0.9633	0.9989	0.9958
JPN	0.9726	0.9992	0.9959
CAN	0.9318	0.9994	0.9967
FIN	0.8275	0.9993	0.9959
ESP	0.9194	0.9997	0.9951
KOR	0.8716	0.9995	0.9960
CHL	0.9425	0.9995	0.9954
ARG	0.9386	0.9990	0.9950
CHN	0.9140	0.9996	0.9944
MEX	0.8927	0.9997	0.9947
BRA	0.9653	0.9998	0.9985
IND	0.9571	0.9995	0.9948

Computational Structure and Performance

Solving the model and conducting the relevant counterfactual exercises is computationally intensive. To optimize performance, I wrote the program in parallel using FORTRAN90. The problem lends itself well to a master-slave parallel programming structure. Each processor node solves a specific country's problem. The master node collects the results, computes relevant arrays and statistics, and, if necessary, sends the results to the slaves for another round. Each iteration takes roughly one day, where the slaves spend the vast majority of time solving the one-shot deviations of the government.

Computing the Counterfactual Exercises

This section describes the algorithm for computing the counterfactual exercises. Recall the firm's entry decision:

$$\frac{1}{1+r} \cdot E[V(x', \mu')|G, \Upsilon] \geq f^e \tag{24}$$

where equation (24) is fundamentally one equation with two unknowns: entry (e) and the fixed cost of entry f^e. For the benchmark model, I had data on firm entry rates for each country in my sample. This simplified computation by not requiring me to calculate equilibrium entry for each level of protection. For the counterfactual exercises I assume that firm entry costs (f^e) have the have the following form:

$$f_i^e = B_i \cdot N_i^{\phi}$$

where B_i is a constant, N_i is the number of firms (varieties) in country i, and $\phi \in (0, 1)$ reflects the increasing difficulty of introducing new varieties. This construction is similar to Luttmer (2007). Alternatively, I could have placed this assumption into preferences along the lines proposed by Benassy (1996) and used by Alessandria and Choi (2007). I believe both approaches are equivalent and chose the cost approach for its simplicity.

Since firm entry is akin to the entry of new varieties/ products in the model, ϕ is similar to the elasticity of new inventions to R&D effort. Researchers find results between results ranging between 0.1 and 0.6. For simplicity, I assume that fixed costs are relatively insensitive to the number of firms in the industry and set $\phi = 0.3$ for all counterfactual exercises.

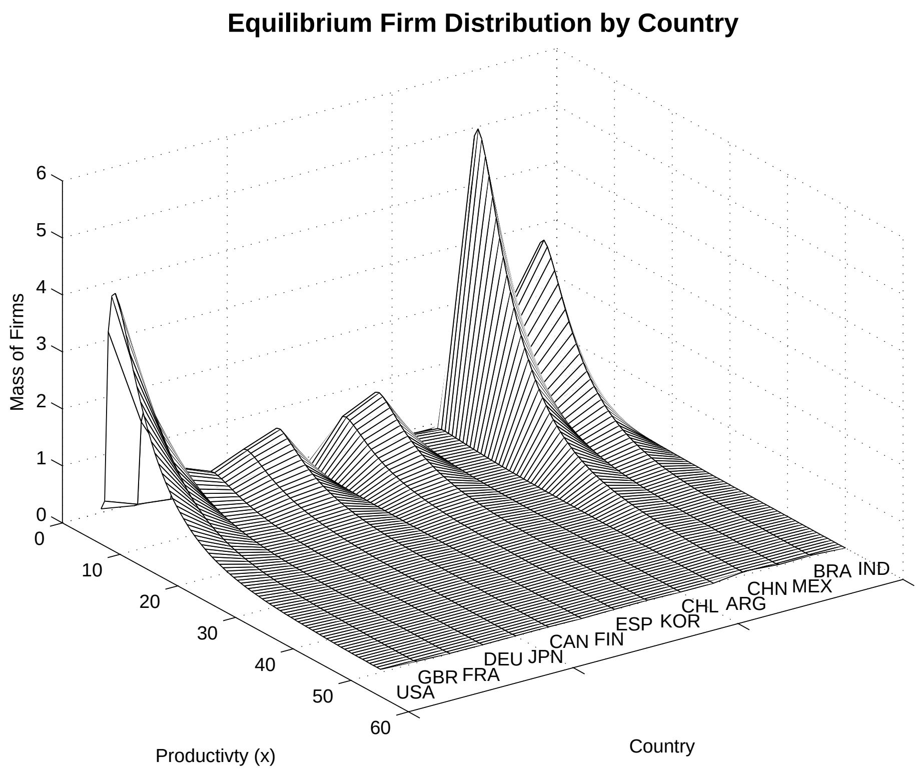
Solving for the new steady-state proceeds along the following steps:

1. Solve the benchmark model using entry rates observed in the data (e). Save the benchmark levels of country welfare.
2. Use the equilibrium value function and initial productivity distribution to solve for firm entry cost f^e
3. Compute the relevant counterfactual exercise using the entry contraction mapping

4. Calculate country welfare given the new level of protection

Firm Distributions Across Countries

The equilibrium firm distributions are detailed in the figure below.



Qualitatively, the distributions exhibit the general characteristics seen in the data: large number of low productivity firms and a small number of high productivity firms. Since I assume that all countries have a common exit rate δ, the firm entry data drives the height of the distribution. Generally, more populous countries tend to have more firms, resulting in height of μ.

Fixed Costs

The fixed entry costs are computed by using equation **??** given data on official firm registrations. Table 13 presents the equilibrium fixed costs implied by the model.

Table 13: Fixed Entry Costs*

Country	Fixed Cost
USA	1.00
GBR	1.88
FRA	1.38
DEU	2.08
JPN	2.30
CAN	0.73
FIN	1.55
ESP	1.13
KOR	1.70
CHL	1.46
ARG	3.04
CHN	3.17
MEX	0.73
BRA	0.88
IND	40.79
mean	4.49

*Relative to USA