International Patenting Frictions

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Abstract

We develop a model of firm decisions to patent in foreign markets that identifies the trade-off between fixed costs of patenting and the profitability of patenting in foreign markets based on market size, trade frictions, and the strength of a patent. The model gives a measure of bilateral patenting frictions and also yields a patent gravity equation. We use the PATSTAT database to develop a measure of the number of patents between country pairs. We then construct measures of bilateral patent frictions from the theoretical model, and estimate a patent gravity equations. We employ recent empirical innovations in the structural gravity literature to consistently estimate the effect of WTO membership on bilateral patent flows.

1 Introduction

During the period from 1980 to 2015, there was a substantial growth in world trade. Reductions in trade and communications costs, combined with reductions in tariff and non-tariff barriers through the WTO and the expansion of preferential trade agreements, resulted in a growth in trade of 2.3% per year. Over the same period, cross border patenting activity grew even faster, with the number of patent applications by foreigners averaging 4% per year over the same period as illustrated in Figure 1.

The reduction in trade barriers was certainly a factor in the rise in patent activity, since better access to foreign markets makes it more likely that firms find it worthwhile to incur the costs of applying for a patent to serve a foreign market. In addition, the adoption of the Trade Related Intellectual Property Rights (TRIPS) agreement as part of the World Trade Organization (WTO) in 1995 led to the expansion of intellectual property rights by member countries. In particular, Figure 1 suggest an acceleration in the growth of international patent applications following the TRIPS agreement.

Our goal in this paper is to develop a model of the sources of international patenting frictions, and to identify the extent to which the growth in international patenting is a result of the reduction in these patenting frictions. As shown by Branstetter et al [1], the transfer of technolgy as a result of strengthening of intellectual property rights (IPRs) can spur economic development. Therefore, it is important to understand the factors that contribute to the expansion of international patenting activity. There is a substantial literature that uses the gravity model of trade to identify the frictions that affect bilateral trade, but much less attention has been paid to the identification of patenting frictions. We model the decision to patent involving a trade-off between the fixed costs of obtaining a patent in a foreign country and the returns that can be obtained from protecting intellectual property in that country. The benefits to the patent depend on the profitability of the foreign market, as reflected in the size of the market and the trade frictions associated with serving the market, as well as on the strength of the patent protection in that market. Using a heterogeneous firm monopolistic competition model, we construct an index of the degree of bilateral patent frictions that depends on the bilateral trade frictions and the bilateral fixed cost of patenting between countries. This measure allows us to provide a comparison of bilateral patenting frictions between countries and how these frictions have evolved over time.

Our model also produces a model of bilateral patenting activity that has the features of a gravity model. Assuming a Pareto distribution of patent productivities, we show that the number of bilateral patents will depend on source and destination country income levels and bilateral trade frictions, as in the trade gravity model. In addition, bilateral patenting activity will be affected by the innovative capacity of the source country and the strength of patent protection in the destination country. The strength of patent protection will depend on the duration of the patent life and the

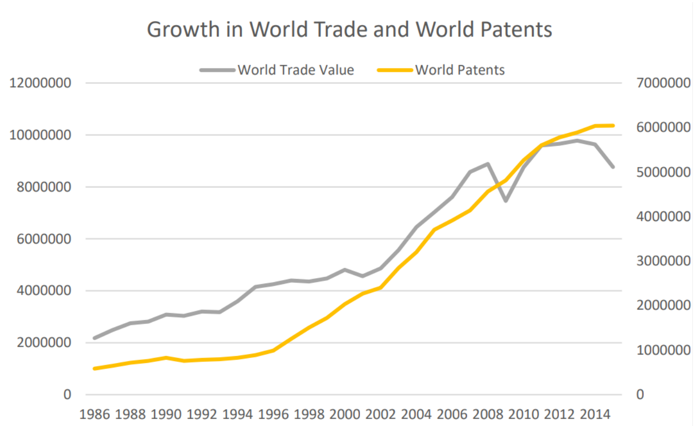


Figure 1: Global patenting growth is both steeper and smoother than trade

level of patent enforcement, where the latter affects the probability that the patent can be infringed without compensation.

We construct measures of bilateral patenting activity using the PATSTAT data set from Spring 2018 obtained from the Euorpean patent office. This data is then used to construct the measures of bilateral patent frictions and to estimate patent gravity equations.

Our work is related to several strands in the literature. Our measure of bilateral patenting frictions is similar to the bilateral trade frictions index developed by Head and Ries [2]. They used used the product of two ratios, the ratio of country i's imports from j to its consumption of its own goods and the ratio of j's imports from i to imports of its own goods, as a measure of bilateral trade frictions. Taking the product of these ratios cancels out common country specific effects, resulting in a measure that depends only on the product of bilateral trade frictions. We use our theoretical model to develop a similar measure based on ratios of patenting activity, and show that this measure is the product of bilateral trade frictions and bilateral patenting frictions. A comparison of the bilateral patenting frictions with the corresponding measure of trade frictions will give an indication of the role of trade frictions in influencing patenting activity.

Our work is also related to the literature on empirical trade gravity equations, which has shown how the value of bilateral trade depends on distance, trade barriers and the size of home and foreign market sizes. Our gravity equations include these variables, as well as factors reflecting the impact of trade agreements on patenting activity. Our empirical analysis utilizes the techniques surveyed by Head and Mayer (2014) and Piermartini and Yotov (2016) for dealing with zeros in bilateral trade data and for the use of fixed effects to control for unobserved variables affecting trade and patent flows.

Our work complements other studies that have analyzed the effect of the TRIPS agreement on patenting activity. Branstatter, Foley and Fisman (2004) [3] use US multinational firm data to study the effects of strengthening IPRs on technology transfer.

Section 2 of the paper develops the theoretical model, which provide the basis for measurement of the bilateral patent frictions and the patent gravity equations. Section 3 describes the PATSTAT data set and provides some stylized facts of international patent flows. We also report results on the bilateral patent frictions. Section 4 discusses the estimation of the patent gravity equations and reports the empirical results. Section 5 offers some concluding results.

2 Model

2.1 A model of the Firm's patent decision

We consider the decision problem for a firm in a monopolistically competitive industry in country i that has developed an idea for producing a new product.

We assume there are N potential national markets in which the product can be sold, with CES preferences in market j given by

$$U_j = \left(\int_{\Omega_j} d_j(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where Ω_j is the set of varieties sold in market j and ω indexes the varieties in that market. The differences in the value of innovations across firms gives rise to a structure of heterogeneous firm monopolistic competition as in Melitz (2003).

If the firm has exclusive right to sell the product in market j, it will earn revenues at time t

given by

$$r_{ijt}(p(\omega)) = p(\omega)d_j(p(\omega)) = \left(\frac{p(\omega)}{P_{jt}}\right)^{-\sigma} E_{jt} \tag{2}$$

where E_{jt} is expenditure and $P_{jt} = \left(\int_{\Omega_j} p(\omega_{jt})^{1-\sigma} d\omega_j\right)^{1/(1-\sigma)}$ the price index in market j. Revenues in j will depend on the number and price of competing varieties in the market, as well as on the overall expenditure level of the destination market.

We assume that output is produced with a constant marginal cost of $\frac{c_{it}}{z(\omega)}$ per unit, where c_{it} is the cost of a unit of factor input and $z(\omega)$ the units of output per unit of input for for variety ω. The quality of the innovation is reflected in the value of z, which can be interpreted as the efficiency of the process for producing the product or as the quality of the new product. We simplify by assuming that the firm knows the value of z at the time it makes the patenting decision in market j. Letting $\tau_{ij} \geq 1$ be the iceberg transport cost of getting the product from i to j, the flow of firm profit will be $(p - c_i\tau_{ij})d_{ijt}$. Profit is maximized by choosing a price $p_{ijt} = \frac{\sigma c_{it}}{1-\sigma}$, which yields profits of

$$\pi_{ij}(z) = \left(\frac{c_i \mu \tau_{ij}}{P_j}\right)^{1-\sigma} \frac{Y_j}{\sigma} = z^{\sigma-1}\overline{\pi}_{ij} \tag{3}$$

where $\mu = \frac{\sigma}{\sigma-1}$ is the markup and $\overline{\pi}_{ijt}$ captures the profitability of market j for a representative firm from i at time t

The existence of a patent gives the firm the right to exclude firms from using the product or process innovation in the market where it is patented. This protection would apply to both domestic and foreign firms that might attempt to infringe on the patent, since foreign firms would be excluded from exporting goods that infringed on the patent. If the firm enters market j without a patent, it has a probability α_j per unit time that it's product will be copied and the monopoly lost. If the firm obtains a patent, the probability that the patent will be infringed on and copied (without compensation) is $\alpha^P < \alpha$. Letting T_j denote the length of patent protection and assuming an expected growth rate of profits γ_j, the gain from obtaining a patent in market j will be

$$\Delta^P_{ijt}(z) = \int_0^{T_j} \pi_{ij}(z)\left(e^{-(r+\alpha_j^P t+\gamma_j)t} - e^{-(r+\alpha_j+\gamma_j)t}\right) dt = z^{\sigma-1}\overline{\pi}_{ij}\Psi_j \tag{4}$$

where $\Psi_j = \frac{(r+\alpha_j+\gamma_j)(1-e^{-(r+\alpha_j^P+\gamma_j)T_j})-(r+\alpha_j^P)(1-e^{-(r+\alpha_j)T_j})}{(r+\alpha_j+\gamma_j)(r+\alpha_j^P+\gamma_j)} > 0$ captures the expected gain in profits with patent protection in market j. The expected growth rate depends on both the growth rate of the market as well as the strength of patent protection. The strength of patent protection will depend on both the duration of protection, T_j, and the strictness of enforcement, which determines α_j^P.

A firm will patent in market j if the expected gain from patenting exceeds the expected cost. We denote the cost of obtaining a patent in market j by F_{ij}. This cost will consist both of fees for obtaining and maintaining the patent and the transactions costs of filing the patent. Since transactions costs may depend on the similarity of the origin and destination markets in factor such as language and institutions, we treat these the cost of a patent as pair specific.

A firm will choose to patent if $\Delta_{ijt}^P(z) \geq F_{ij}$, patenting of a new product from i will be patented in j if

$$z \geq \underline{z}_{ij} \equiv \left(\frac{F_{ij}}{\Psi_j \overline{\pi}_{ij}}\right)^{\frac{1}{\sigma-1}} = \frac{c_i \mu \tau_{ij}}{P} \left(\frac{Y_j \Psi_j}{\sigma F_{ij}}\right)^{\frac{1}{1-\sigma}} \tag{5}$$

The critical value for patenting is increasing in the level of source country costs, c_{it} increasing in the bilateral trade and patenting frictions, $\tau_{ij} F_{ij}^{1/(\sigma-1)}$, and decreasing in the profitability of market j, $\Psi_j E_{jt} P_{jt}^{\sigma-1}$.

2.2 Bilateral Patent Flows

We obtain the bilateral patent flows by aggregating over the firms decisions. Firms in each country engage in R&D that generates ideas for new products. The quality of the new product ideas is assumed to be described by a Pareto distribution, $G_i(z) = 1 - \left(\frac{z}{b_i}\right)^{-\theta}$ for $z \geq b_i$. [1]

The probability that a firm from i patents a new idea in country j is

$$1 - G(\underline{z}_{ij}) = \left(\frac{\underline{z}_{ij}}{b_i}\right)^{-\theta} \tag{6}$$

[1]The value of patents has been measured based on surveys, citations, and licensing revenue. These measures all suggest that the value of patents is highly skewed, so their value is typically modeled using a Pareto or lognormal distribution.

The parameter b_i is the lower bound of the distribution, so a higher productivity for country i innovators is reflected in a larger value of b_i. The parameter θ captures the shape of the distribution - a higher value is associated with a lower spread of the distribution. In order for the expected profits from a market to be bounded, we must have $\theta > \sigma - 1$.

If we assume that the output of new products in country i is ι_i, the number of patents from i to j, N_{ij} will be

$$N_{ij} = \iota_i \left(\frac{b_i P_j}{\mu c_i \tau_{ij}} \right)^{\theta} \left(\frac{Y_j \Psi_j}{\sigma F_{ij}} \right)^{\frac{\theta}{\sigma-1}} \tag{7}$$

The number of patents will be an increasing function of the destination market size, $\frac{Y_j \Psi_j}{P^{1-\sigma}}$, an increasing function of the innovative capacity and cost in the source country, $\iota c_i^{-\theta}$, and decreasing in the level of bilateral trade and patenting frictions, $\tau_{ij} F_{ij}^{1/(\sigma-1)}$.

To identify the magnitude of frictions in bilateral patenting, we can follow an approach similar to that of Head and Ries for calculating bilateral trade frictions. Taking the ratio of the number of patents of i firms in j's market relative to those by j firms in their own market cancels out the common market characteristics of the j market, which yields

$$\nu_{ij} = \frac{N_{ij}}{N_{jj}} = \left[\frac{\iota_i}{\iota_j} \left(\frac{b_i}{b_j} \right)^{\theta} \right] \tau_{ij}^{-\theta} f_{ij}^{\frac{-\theta}{\sigma-1}} \tag{8}$$

The first term in brackets reflects the relative output of patentable ideas in i to j, which depends on the relative level of innovative activity, $\frac{\iota_i}{\iota_j}$ and the relative productivity of their R&D processes, $\frac{b_i}{b_j}$. The remaining terms are the trade fractions between i and j, τ_{ij}, and the relative patent frictions between i and j, $f_{ij} \equiv \frac{F_{ij}}{F_{jj}}$.

In order to focus on the magnitude of bilateral frictions, we can eliminate the relative output of patentable ideas by taking the product of ν_{ij} and ν_{ji}, which yields

$$\nu_{ij}\nu_{ji} = (\tau_{ij}\tau_{ji})^{-\theta} (f_{ij} f_{ji})^{\frac{-\theta}{\sigma-1}} \tag{9}$$

Assuming that the elasticity of substitution, σ, and the shape of the Pareto distribution, θ, are constant over time, (9) will be an inverse measure of the level of frictions to international patenting over time. These frictions reflect both the bilateral trade friction and the bilateral frictiosn in patenting. n trade and patent cost frictions. Equation (9)

The trade frictions and patent frictions will not necessarily be symmetric. Trade frictions include both transport costs and tariffs, and the latter could be asymmetric between country pairs. Patent frictions could also be asymmeric, since firms from one country will not necessarily face the same transactions costs of getting lawyers. In principle there is no discrimination between domestic and foreign firms due to the requirement of national treatment in patenting, but such discrimination could also contribute to patent frictions.

2.3 A Patent Gravity Equation

The measures of bilateral patent frictions capture how trade costs and the fixed costs of patenting have changed over time. However, they do not allow us to capture the effects of non-discriminatory changes in patent protection, because factors that are common to all firms in a market are differenced out in construction of (9). Capturing these factors requires direct estimation of (16).

Equation (7) can be thought of as a patent gravity equation, since it takes a from similar to that in a trade gravity equation,

$$logN_{ijt} = \beta_0 + log\iota_i - \theta log\left(\frac{c_i\tau_{ij}}{b_iP_j}\right) - \frac{\theta}{\sigma-1}log\left(\frac{F_{ij}}{E_j\Psi_j}\right) \tag{10}$$

As in the trade gravity equation, we can decompose the expression into source market effects, destination market effects, and bilateral friction effects.

The destination market effect involve the destination market expenditure, E_j, and the multilateral resistance effects captured in P_j, as in the trade gravity equation. In addition, patents will be increasing in the the degree of destination market patent protection and local market growth rate, which are captured in Ψ_j.

The origin market effects are reflected in the term $\iota_i\left(\frac{c_i}{b_i}\right)^{-\theta}$. In the trade gravity equation, the factor market equilibrium condition can be inverted to express the factor price, c_i, as a function of origin country capacity, $\frac{X_i}{\Omega_i}$. Origin country capacity reflects the size of domestic income, X_i, as well as the existence of alternative markets for home country output. In the patent gravity equation, there is an additional term reflecting the origin country's level of innovative activity and productivity in R&D.

The coefficient on bilateral tariff and transport cost, τ_{ij}, is the parameter θ from the Pareto distribution, as in the trade gravity equation. The coefficient on fixed patent costs and income will involve both θ and σ. We discuss the estimation of (10) in detail in section .

In light of the potential for zeros in the bilateral patent data, it is preferred to estimate (16) using

$$N_{ijt} = \exp[o_{it} + \delta_{jt} + d_{ij} - \theta ln\tau_{ij} - \frac{\theta}{\sigma - 1} lnF_{ij}] + \epsilon_{ijt} \tag{11}$$

where o_{it} is an origin time fixed effect, δ_{jt} is a destination time fixed effect, and d_{ij} is the time invariant pair effect. The d_{ijt} captures factors such as distance and colonial ties that may effect trade and patent frictions, but do not vary over time.

The application to patenting behavior does involve some additional factors to the source country, destination country, and pair effects that are not present in the trade gravity equation. The destination market size involves both income, Y_j, and multilateral resistance effects, P_j that are familiar from the trade application, but it also includes a measure of the strength of patent protection in the domestic market, Ψ_j. In the standard trade gravity model, the source country factor will be determined by the source country's share of world income and a mulitilateral resistance, which is a reflection of the demand for the source country's factor inputs. This term is obtained by substituting for c_i from the home country revenue equation. In the case of patents, the source country effect involves the domestic innovative capacity, ι, as well the demand for factors in production. As is now standard in the estimation of gravity equations, the source and destination market effects can be captured by including source and destination fixed effects.

3 Data

A traditional gravity analysis requires trade flow data from country to country during a given time period (along with any covariate of interest). Our analysis requires similar measures but regarding patent application flows rather than trade volumes. Typically, annual data is used due to its availability for many of the covariates used in the regressions, i.e GDP, population. Our empirical analysis uses data spanning 36 years from 1980 to 2015 and covers 211 countries and territories. We use the PATSTAT [4] database from the EPO to construct aggregate patent application flows by origin-destination-year. We merge those measures with a standard gravity panel provided by Head and Meyer (2001) [5] including indicators of existing FTA's, WTO membership, etc.

PATSTAT

The PATSTAT database is maintained by the European Patent Office. It is collected from national patent offices and incorporated into a unified SQL database. The database is updated and distributed biannually, we use the Spring 2018 release. Each primary entry in the database is a patent application along with many of its characteristics like date and type of application. While the data technically stretches back to the 1800's, we limit our analysis to post 1980, this is due to the relative sparsity of data prior to 1980. We also cut off our data at 2015 despite having data up to 2018, this is because patent data can take several years to "mature," i.e. a single innovation may take several years to acquire patent protection in various countries.

Applications fall primarily into two categories, "patents of invention" or "utility models." While both types require "novelty, usefulness, and non-obviousness," a utility model requires them to a lesser degree, usually representing an incremental advancement rather than a new innovation. We limit our analysis to only patents of invention to capture innovation flows rather than small improvements. The restrictions this places on the sample are shown in Table 1.

	Full Sample	Years 1980-2015	Patents of Invention	Patents of Invention 1980-2015
# Patent Applications	99,298,592	62,926,896	82,147,980	52,031,026

Table 1: Data restrictions by date and type

Notably, each application has an "authority," the jurisdiction in which patent protection is being sought. We refer to each application's country of authority as its "destination." Applications also have a list of applicants along with their addresses which we use to determine the origin of each application. A complicating factor is that a single innovation can be patented in many countries but has only one origin. We solve this issue by grouping the applications into "patent families" and determine the origin thereof. Note that though the term "patent family" suggests a collection of similar innovations, it refers to a collection of applications for the *same* innovation in several countries. We form these groups using the notion of priority.

When the first application for an innovation is made (anywhere in the world) it is granted "priority" which allows a period of time during which no other party may seek a patent for that innovation anywhere else in the world. The Paris Convention for the Protection of Industrial Property (1883) [6] determined the length of the priority period to be 12 months. The Patent Cooperation Treaty of 1970 [7] (enforced beginning in 1978) extended that period to 30 months but only for "international applications" which function only to establish priority. Regardless of which treaty it may fall under, any application for patent protection of the same innovation is linked to that innovation's priority application. The size of the resultant patent families provide some insight into patenting behavior. Most innovations are only patented once, 76% of all patent families contain only one application. The distributional shape of the number of applications in a family is shown in Figure 2. The average number of patents in a patent family over the whole sample is 1.89. Conditional on being patented in a least 2 countries however, gives a mean family size of 4.65.

Note that the origin of an innovation is not simply the country of authority of the priority application. It is fairly common for innovators to file first for a patent in a county besides their home country. For example, it is particularly prominent for Canadian innovators to choose to patent in the U.S. before Canada. Within a patent family (linked together by priority), we determine the origin with the addresses of the applicants for the priority patent application. Frequently, there are multiple applicants for a single application and, occasionally, the addresses of those applicants are in different countries. To determine which country is the origin, we compare the "type" of applicant.

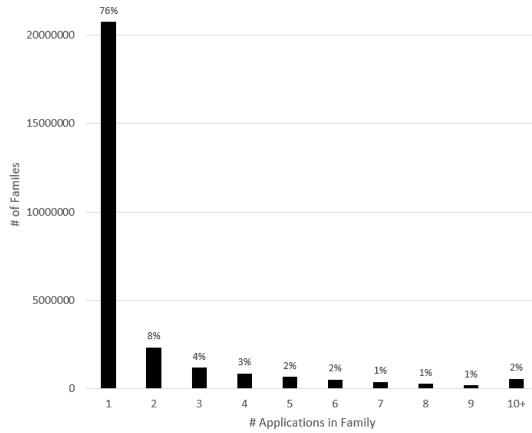


Figure 2: Distribution of the number of applications per patent family

We give priority based on economic significance: 1st, Company or Government; 2nd, University or Hospital; 3rd, Non-profit or Individual. In select cases, there is still ambiguity concerning the origin, in those cases we resolve the tie using the order in which applicants are listed on the application. Table 2 provides a breakdown of how frequently the different tie-breaking procedures were needed for the PATSTAT data. Using this method, we can assign an origin to a majority of applications but only around half of patent families. This discrepancy is largely caused by innovations that were only ever placed in a single country. To address this issue, we also construct the "priority destination" for each innovation. This is simply the country of authority of the priority patent, this must exist for every innovation. The "priority destination" seems to be a good approximation for the origin assignment, among the patents (innovations) that have an origin assigned. The breakdown of origin and priority destination coverage is given in Table 3.

No Tiebreaker Needed	Applicant Type Tiebreaker	Applicant Order Tiebreaker
23,564,483 ($\approx$ 93%)	1,783,314 ($\approx$ 7%)	Still working on

Table 2: Origin assignment tiebreakers frequency

With an origin assigned to each application, we construct aggregate patent application flows from

Applications	Patent Families	Applications w/ Origin	Patent Families w/ Origin	Applications w/ PriDest	Patent Families w/ PriDest	Applications Matching	Patent Families Matching
111,217,594	28,268,915	96,573,492	13,687,681	111,036,071	28,087,392	96,187,610	13,621,250

Table 3: Origin coverage and Priority Destination matching. Note: at the moment, this table is not correctly date restricted, the numbers are very close to correct.

country i to country j in year t, N_{ijt}. With these aggregates we can construct the aforementioned Head and Ries (2014) [2] measures of patenting frictions between two countries.

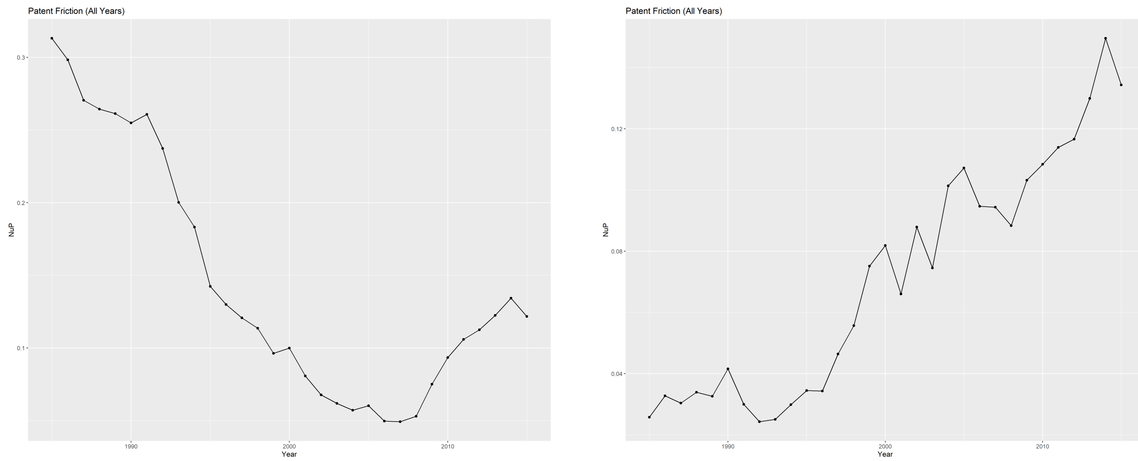
$$\frac{N_{ij}}{N_{jj}}\frac{N_{ji}}{N_{ii}} = (\tau_{ij}\tau_{ji})^{-\theta}(f_{ij}f_{ji})^{\frac{-\theta}{\sigma-1}} \tag{12}$$

Note that the way the measures are constructed means that a higher number implies a lower barrier to patenting (higher cross market patenting relative to domestic patenting). In Figure 3, we show the evolution of this friction measure over time in two pairs of countries. Panel a) shows the frictions between the U.S. and Japan as they decrease. This illustrates that there are increasing barriers to cross market patenting between the U.S. and Japan. On the flipside, panel b) shows that barriers to patenting are falling between the U.S. and Austria (fairly representative of the major European economies).

Gravity Variables

The Head and Meyer gravity panel dataset provides traditional explanatory variables like distance between countries and GDP of origin and destination. It also provides indicators of the existence of free/regional trade agreements between two countries each year along with the primary covariate of interest, membership in the WTO (and consequently, TRIPS). Membership in the WTO potentially impacts desirability of a patent in a country through several channels, i.e. increased patent protection and decreased barriers to other forms of trade.

To isolate the impact of increased patent protection, we construct a variable indicating whether TRIPS is binding between two countries each year. This is notably distinct from WTO membership



(a) U.S. and Japan

(b) U.S. and Austria

Figure 3: Patenting frictions in a country pair over time

due to a provision in the TRIPS agreement allowing developing and “least-developed” countries a transition period during which to bring their intellectual property protection system into TRIPS compliance. The transition periods are only granted to original members of the WTO, any other transition periods would have to be negotiated individually. Developing countries were allowed until 2000 to comply, least-developed countries were given until 2013. Note that these dates indicate the latest that these countries became compliant, it is entirely possible that they were compliant before the end of the transition period. To address this issue, we utilize the Fraser freedom index (FFI) [8] which provides a measure of the overall economic freedom in a given country at any point in time. The FFI is constructed with several sub-indices, one of which deals with the “legal system and property rights” in each country. The FFI provides a good means to estimate the impact of property rights on firms behavior, it is limited however once we employ country-time fixed effects because it does not vary across origin countries.

To form the desired comparisons between patenting and trade behavior, we use gross bilateral exports from OECD.Stat [9]. As a simple illustration of the relative desirability of a destination for patents v.s exports, we construct p_{ij}^{share}, the share of all patents from country i going to country j (similarly for exports, x_{ij}^{share}). Note that t is excluded because we are aggregating over the years

2005-2015.

$$p_{ij}^{share} = \frac{Nij}{\sum_j N_{ij}}, \qquad x_{ij}^{share} = \frac{Xij}{\sum_j X_{ij}} \tag{13}$$

Figure 4 shows x_{ij}^{share} plotted against p_{ij}^{share} for the U.S. (panel a)) and China (panel b)). Several things are apparent from the two graphs. The upward trend indicates that countries that are attractive for trade are correspondingly attractive for patenting. Deviations above the 45° line indicate that a country is more attractive for trade than patenting, and vise versa for below the 45°. Panel a) reveals the significance of U.S. trade with Mexico and Canada despite not placing a commensurate number of patents in either. For both the U.S. and China, countries in the EU receive a large number of patents relative to exports. This is likely due to the partially unified nature of the EU patent system in which a single application can be submitted to the EPO for protection in any number of EU members. Both graphs also display that patenting behavior varies across destination and, while related, is not entirely driven by trade.

We can denote by η_{ijt}^{p} the value of the bilateral trade friction index (9) at time by t. In view of the large number of bilateral comparisons involved, we would like to find a method for summarizing the changes over time in the index of patent frictions. One way to do this is to regress the constructed measures on destination country time, source country time, pair fixed effects, and a random effect:

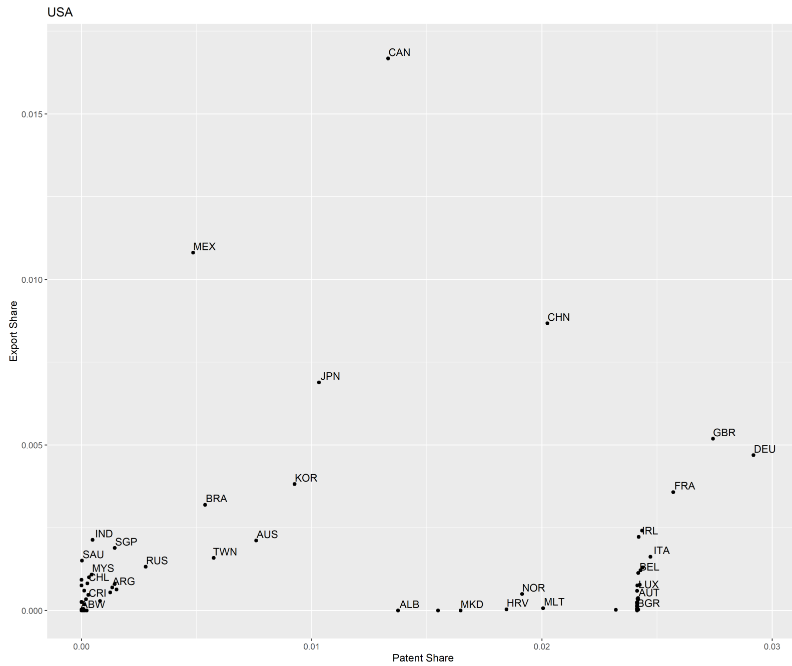
$$\eta_{ijt}^{p} = \delta_{i,t}^{p} + \delta_{j,t}^{p} + \delta_{ij}^{p} + \varepsilon_{ijt}^{p} \tag{14}$$

We will do analysis of this type to study the evolution of bilateral patenting frictions over time.

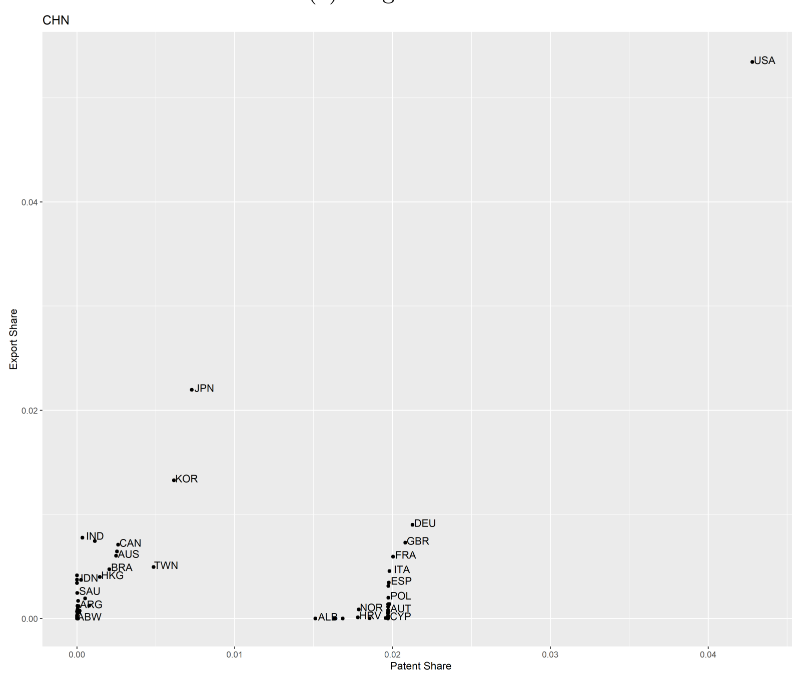
Letting η_{ijt}^{r} denote the corresponding Head-Ries index based on trade volumes alone, we can perform a similar decomposition for the trade effects.

$$\eta_{ijt}^{hr} = \delta_{i,t}^{hr} + \delta_{j,t}^{hr} + \delta_{ij}^{hr} + \varepsilon_{ijt}^{hr} \tag{15}$$

The relationship between the evolution of trade frictions and the evolution of our measure of patenting frictions will provide an indication of the role of fixed costs of patenting.



(a) Origin = USA



(b) Origin = China

Figure 4: Share of patents vs. Share of exports to each destination

4 Empirical Strategy

In section 2, we derived an equation relating aggregate patent application flows between countries to aspects of that country pair:

$$N_{ij} = \iota_i \left(\frac{b_i P_j}{\mu c_i \tau_{ij}}\right)^{\theta} \left(\frac{Y_j \Psi_j}{\sigma F_{ij}}\right)^{\frac{\theta}{\sigma-1}} \tag{16}$$

To identify the effects of various features of interest, we take guidance from Piermartini and Yotov (2016) [10] which provides an assortment of pitfalls when dealing with trade data in a gravity setting. Fortunately, they also provide solutions to these problems. The issues are raised in the context of trade flows, but they are equally (if not more so) applicable to patent application flows. The most prominent feature of the data is the prevalence of zeros in aggregate patent application flows, particularly between smaller countries. This poses a problem for any method that requires log-linearization. Potential solutions to this issue include censoring the data to include only larger countries that do not have zeroes in the bilateral patent flows or removing individual zero observations. Both solutions remove a significant amount of information and ignore the meaning of a zero in the patent flows. Another method to eliminate zeros is to add 1 to all observations, this understandably produces a significant bias in estimates. We turn to the approach in Silva and Tenreyro (2006) [11], the Poisson pseudo-maximum likelihood estimator (PPML). By avoiding the need to linearize the specification, zeros do not pose a problem.

The second facet of trade data that is even more true of patent data is the heterogeneity. Specifically, the variance in patent flows between large countries is correspondingly larger than that between smaller countries. If unaddressed, heteroskedasticity has the potential to induce a large bias in estimates. Yet again, the PPML provides a solution that completely avoids the problem. The only requirement for the PPML to provide consistent estimates is for the conditional mean to be correctly specified, the conditional variance can be anything. The traditional Poisson assumption is that the conditional variance is equal to or directly proportional to the conditional mean. In practice, the conditional variance of patent data seems to be a higher order of the conditional mean, with the variance of patent flows between large countries disproportionately larger than that of smaller county pairs. Econometrically, this suggests an estimator that gives less weight to the larger observations due to their higher variance. Another consideration, however, is the quality of the data, we expect that the data from the larger countries is more reliable. A happy medium between the econometric and data concerns is to accept the traditional assumption of direct proportionality.

To control for the unobservable "multilateral resistances" like MFN tariffs, average legal costs in a country, formal application costs, etc. we employ origin-year and destination-year fixed effects. This unfortunately eliminates our ability to estimate the effects of other interesting covariates like distance, GDP, GDP/Cap, the Fraser freedom index, and anything else that does not vary within a year-country pair. Fortunately, this does not disqualify the inclusion of trade policies, specifically joint membership in the WTO and bilateral trade agreements. Another potential problem is the endogeneity of those policy decisions, some preexisting relationship between two countries that drives both patent flows and trade policies. We include origin-destination fixed effects to alleviate this concern, this eliminates the possibility of policy endogeneity but also disqualifies other bilateral characteristics from the any regression, i.e. distance, common language, etc. Including all three types of fixed effects significantly limits what can be included in each regression, but makes the estimates of the trade policy effects more robust. Until recently, the use of all three types of fixed effect combined with PPML estimation was too computationally costly to be feasible. Larch, Wanner, Yotov, and Zylkin (2018) [12] provides a solution to this problem with an iterative estimation approach using all three FE's and PPML. They manage to estimate the standard errors as well by extending the approach suggested in Figueiredo, Guimaraes, and Woodward (2015) [13] to three sets of fixed effects. Figueiredo, Guimaraes, and Woodward (2015) exploits the fact that the variance-covariance matrix from a poisson regression is proportional to that of an appropriately weighted linear regression so that they can apply the Frish-Waugh-Lovell theorem.

4.1 OLS

We begin our analysis with the simplest specification, the log-linearized OLS. This specification has concerns as mentioned previously, but provides a useful benchmark when comparing to similar estimates using trade flows. This naive specification outputs coefficients in line with what one would expect for various covariates, i.e. distance has a negative impact while GDP's have a positive impact. Table 4 provides a comparison of estimation results for patent flows vs. trade flows using the specifications in equations 17 and 18 respectively. We use gross bilateral exports, X_{ijt}, as a measure of trade, the data was acquired from OECD.Stat and spans the years 2005-2015.

$$ln(N_{ijt}) = o_{it} + \delta_{jt} + d_{ij} + \beta ln(GRAV_{ijt}) + \epsilon_{ijt} \tag{17}$$

$$ln(X_{ijt}) = o_{it} + \delta_{jt} + d_{ij} + \beta ln(GRAV_{ijt}) + \epsilon_{ijt} \tag{18}$$

where o_{it}, δ_{jt}, and d_{ij} fixed effect (where included) and $GRAV_{ijt}$ is a vector of gravity covariates.

A relatively surprising feature of this regression is the negative coefficient on TRIPS binding, this coefficient is persistently negative across different specifications and we discuss possible reasons for this later on. A more direct measure of the strength of a patent system is the Fraser Freedom Index (FFI). The FFI is published by the Fraser Institute as a measure of economic freedom in each country. One of the components that makes up this index is a measure of the strength of a country's legal system and property rights (LSPR). In any specification without country-time fixed-effects, we are free to include the FFI_LSPR to gauge the impact of a strong patent system on patent flows to a destination. As expected, but in contrast to the estimate for TRIPS, the impact of a developed legal rights system is strong and positive.

The focus of this regression are the estimates on WTO membership and FTA's between countries, both of which have a positive impact on patent flows. Noticeably, joint EU membership has a large effect. The EU is unique in that innovators can apply for patent protection in several countries with a single application. This type of application typically designates a large number of the smaller countries in eastern Europe. Many This comes largely from the smaller countries that are part

	Patents			Trade	
	OLS	w/ IPR	w/ Fe's	OLS	w/ FE's
WTO	0.149***	0.287***	0.513***	-0.143**	0.144
	(0.016)	(0.036)	(0.042)	(0.055)	(0.333)
TRIPS		-0.218***	0.003		
		(0.032)	(0.037)		
FFI		0.193***			
		(0.014)			
Currency	0.303***	0.455***	-0.135***	-0.399***	0.140
	(0.049)	(0.056)	(0.027)	(0.05)	(0.089)
FTA	0.365***	0.227***	0.165***	0.066	1.765***
	(0.023)	(0.031)	(0.014)	(0.048)	(0.04)
EU	1.263***	1.232***		0.114***	
	(0.031)	(0.042)		(0.041)	
ln GDP_o	0.538***	0.571***		0.998***	
	(0.004)	(0.006)		(0.009)	
ln GDP_d	0.315***	0.234***		0.951***	
	(0.005)	(0.007)		(0.008)	
ln GDP/Cap_o	0.523***	0.539***		0.001	
	(0.006)	(0.008)		(0.012)	
ln GDP/Cap_d	0.368***	0.244***		0.015	
	(0.007)	(0.017)		(0.013)	
ln Distance	-0.182***	-0.193***		-0.838***	
	(0.009)	(0.013)		(0.024)	
Language	0.084***	-0.032		0.797***	
	(0.019)	(0.026)		(0.043)	
Colony	-0.059	-0.037		0.970***	
	(0.055)	(0.071)		(0.104)	
Border	0.630***	0.533***		0.599***	
	(0.032)	(0.046)		(0.068)	
constant	-26.132***	-24.889***	2.254***	-24.610***	18.422***
	(0.182)	(0.241)	(0.029)	(0.394)	(0.301)

Table 4: Comparison of gravity estimates for Patents vs. Trade flows using OLS

of the EU that There are some noticeable differences between the estimates for patent flows and trade flows. One of these differences is the larger impact of EU membership on patent flows than trade flows. This is an artifact of the European patent system. Unlike elsewhere in the world, the EU awards an international patent that provides protection in each country indicated on the application (naturally, limited to EU members). Because of the ease of adding countries to such an application, many of the smaller countries in the EU have a large number of patent applications. Another interesting facet of these estimations is the relatively smaller impact of GDP on patent flows. The coefficients on GDP for trade flows falls perfectly in line with the common unitary result, a 1% increase in GDP results in a 1% increase in trade. A third point of interest is the smaller role of distance in determining patent flows. While it is to be expected that distance is less of a factor when considering the transfer of IP rather than physical goods, the degree to which they are different is notable with the coefficient for patent flows barely 20% that of trade flows.

One of the primary mechanisms for exploiting the monopoly granted by a patent is to export the patented good to the destination where it is patented. The differences in these key variable coefficients highlights that the decision to patent is distinct from the decision to export despite their close linkage.

4.2 PPML

The OLS regressions provide some descriptive intuition and a nice comparison to trade data, but it has several key problems when applied to trade data, enumerated earlier in this paper. We turn to the PPML estimator to deal with those issues. Like before, we present results for both patent and trade flows with and without fixed effects in Table 5. For clarity, the non-linear specifications for the ppml regressions are given in equations 19 and 20.

$$N_{ijt} = \exp[o_{it} + \delta_{jt} + d_{ij} + \beta GRAV_{ijt}]\epsilon_{ijt} \tag{19}$$

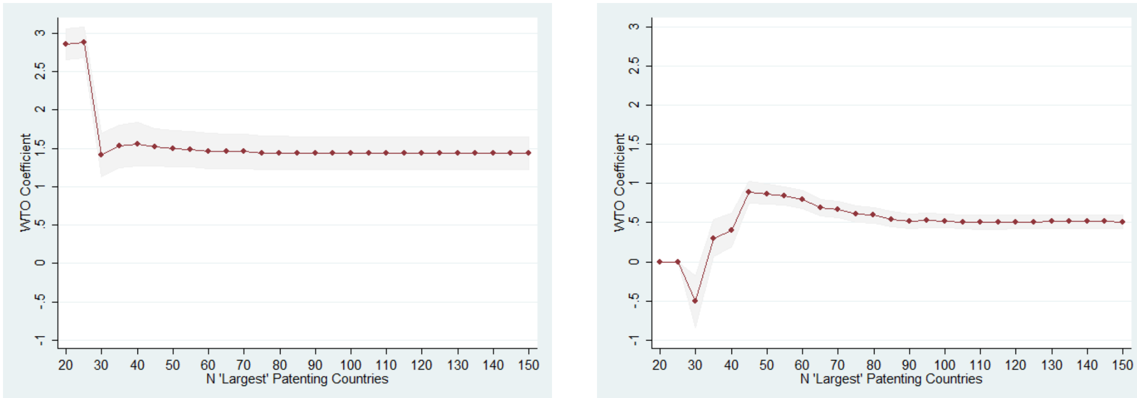
$$X_{ijt} = \exp[o_{it} + \delta_{jt} + d_{ij} + \beta GRAV_{ijt}]\epsilon_{ijt} \tag{20}$$

The PPML regression reveals a much greater significance for WTO membership for patent flows than the log-linearized regression gave. It also reduces its effect on trade flows to insignificance. Both of these results are consistent with recent literature on the impact of WTO membership. Dutt et al. (2013) and Roy (2011) find the effect on imports and exports to be either mixed or non-existent once country-time fixed effects are included. [12] Larch, Monteiro, Piermartini, and Yotov (2019), however, focus on the "intangibles" of WTO membership and find that WTO membership increases average trade (between members) by 171%. These intangibles (reduced trade uncertainty, increased property rights, etc.) are closely linked to what is important for patenting. It is unsurprising then to see our WTO coefficient falls in line with the Larch et al. estimate. As a caveat to this result, the coefficient on TRIPS is fairly large but negative. For many larger countries and any country joining after the beginning of the WTO, there is no difference between WTO membership and TRIPS enforcement. For those countries, the net coefficient of joining those treaties is closer to 0.5. The reason for the negative coefficient on TRIPS could be due to the delay in its enforcement. If there exists a large stock of innovations that have not yet diffused to a country entering the WTO, there may be an immediate surge of patents into that country. The negative coefficient on TRIPS could be a reflection of the relatively large influx of patent applications following WTO accession having died down by the TRIPS deadline. This question requires further study of the firm level timing decisions of patenting in various countries.
Another significant difference between the patent and trade estimates is for GDP per capita in both origin and destination. The effect of GDP/Capita is substantially larger on patent flows, this could be due to a homotheticity in demand, as individuals have more wealth they demand more of the type of good that would be patent protected. On the origin side, this could be interpreted as an increase in individual wealth resulting in a comparative advantage in innovation.

One of the key features of the PPML estimation is it's robustness to heteroskedasticity in the data. We illustrate this by iteratively running the estimations with more countries beginning with the largest (most active in patenting) and incrementally adding smaller countries. We present the estimates for the effect of joint WTO membership in Figure 5. Both methods require more than a

	Patents			Trade	
	PPML	w/ IPR	w/ Fe's	PPML	w/ FE's
WTO	1.61***	1.354***	1.433***	0.148**	0.610
	(0.067)	(0.102)	(0.109)	(0.057)	(0.539)
TRIPS		-0.034	-0.903***		-0.629
		(0.054)	(0.108)		(0.471)
FFI		0.301***			
		(0.022)			
FTA	0.182***	0.012	0.103***	0.066	1.902***
	(0.051)	(0.064)	(0.02)	(0.059)	(0.076)
Currency	0.09*	0.165*	0.099***	-0.044	-0.352**
	(0.05)	(0.059)	(0.015)	(0.05)	(0.158)
EU	0.124***	0.177***		-0.227***	
	(0.048)	(0.066)		(0.055)	
ln GDP_o	1.107***	1.081***		0.808***	
	(0.01)	(0.012)		(0.016)	
ln GDP_d	0.442***	0.325***		0.886***	
	(0.011)	(0.015)		(0.018)	
ln GDP/Cap_o	0.577***	0.613***		-0.123***	
	(0.016)	(0.017)		(0.028)	
ln GDP/Cap_d	0.454***	0.203***		-0.108***	
	(0.016)	(0.03)		(0.02)	
ln Distance	-0.462***	-0.467***		-0.692***	
	(0.024)	(0.033)		(0.034)	
Language	-0.319***	-0.478***		0.378***	
	(0.042)	(0.055)		(0.053)	
Colony	-0.501***	-0.401**		0.835***	
	(0.14)	(0.155)		(0.113)	
Border	-0.141***	-0.111*		0.325***	
	(0.048)	(0.064)		(0.059)	
constant	-43.64***	-39.36***		-16.402***	
	(0.409)	(0.513)		(0.769)	

Table 5: Comparison of gravity estimates for Patents vs. Trade flows using PPML



(a) Using PPML

(b) Using OLS

Figure 5: Estimates for WTO using increasing number of countries

small handful of countries to produce stable results, but the PPML approach requires fewer. Panel a) illustrates the stability of the PPML estimates as smaller countries are included and the overall heterogeneity of the data increases. The PPML estimate stabilizes with only around 30 countries, further additions affect the estimate only slightly. Panel b) shows the same estimates from the OLS specification. As more countries are added the OLS estimates drift quite a bit, finally stabilizing after nearly 100 countries are included.

5 Conclusion

The data bears out the story that global patenting conditions are changing. We find that the major international treaties governing patenting and intellectual property at a broader level are a major influence in that change. WTO membership increases the flow of patents to a country by an average of ≈160%. Even considering the amended estimate given the relationship between TRIPS and the WTO, accession to those treaties boosts incoming patent flows by around 50%. The analysis also highlighted some key differences between trade flows and patent flows. Specifically, patent flows are less affected by total country income and more by individual wealth.

One of the large contributions of this paper is the method by which an origin is assigned to each patent family. This assignment will be useful in subsequent research that deals in patent flows, whether it be timing decisions or aggregate patent application count. Further data work will be to assign industry codes to each patent application. This will be an exercise in unifying various national industry classification systems as well as filling in missing data based on other patent characteristics. Once this is done, we can perform a similar analysis on disaggregated industries to capture specific features of a country's IP system.

The model studied in this paper is limited to firm level incentives for profit. The model does not consider the motives of the countries involved. It may not be in a country's best interest to provide "strong" patent protection. While they may not receive many patent applications, they are then free to imitate the innovation without consequence. The welfare tradeoffs of strong vs. weak patent systems have been studied elsewhere in the literature and would be interesting to incorporate in this model to study welfare effects of various treaties.

Finally, this paper takes the innovating level in each country (ι_{it}) as exogenous. Further work can be done to endogenize R&D intensity. The changes in optimal ι_{it} in response to various shocks or treaties would provide another opportunity for a welfare type analysis.

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