Regional Trade Agreements and International Patenting along the Supply Chain*

Jesse LaBelle
FRB of St. Louis

Inmaculada Martinez-Zarzoso
University of Göttingen and Universitat Jaume I

Ana Maria Santacreu
FRB of St. Louis

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Abstract

We construct a new dataset of bilateral patenting flows to study the determinants of international patenting across industries. We document salient features of international patenting and study the role of regional trade agreements with technology provisions. We find that several Asian countries have risen as both origin and destination of patenting activity. Regional trade agreements have a positive and statistically significant impact on bilateral patenting flows. We find around 22% more international patenting activity for RTA members in comparison with non-members.

*The views in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of St. Louis or the Federal Reserve System.

1 Introduction

Globalization has transformed the structure of production into complex networks through which firms exchange not only goods and services, but also technology and ideas. In such an interconnected world, inventors seek protection for their ideas globally. One channel to obtain such protection is through foreign patent applications. Because patents are territorial—i.e., they only offer protection in the jurisdiction in which they have been granted—inventors have an incentive to patent in many countries. However, applying for a patent is costly, both in terms of money and time. Hence, applicants may choose to patent in specific countries to which they are connected through input-output linkages.

The new trends in the structure of production are also reflected in trade policy. While prior to 1995 most trade agreements were about reducing tariffs, the majority of current trade agreements include technology provisions to ensure intellectual property (IP) is protected internationally.[1] In this paper, we document several features of industry-level international patenting flows and explore the role of regional trade agreements with technology provisions on the observed patterns of patenting across countries and industries.

We begin by constructing a new dataset of patenting flows across countries and industries for the period 1980-2019. We use data from PATSTAT to compute yearly industry-level patent applications from a country of origin to an application authority. Our database differs from other publicly available datasets in that it is more comprehensive in the number of patent authorities it encompasses and includes the industry dimension. The main advantage is that it can be used to address a broader set of questions, capture the recent rise of new powerhouses of innovations (i.e, China), and uncover the existence of technology supply chains based on where firms seek for protection for their inventions along the chain.

We then use our new dataset to study the effect that regional trade agreements (RTAs) with technology provisions have on international patenting flows. Our measure of RTAS with technology provisions is from Martínez-Zarzoso and Chelala (2021). The main framework for empirical analysis is a gravity model that uses international patenting flows for the period 1995-2019 as dependent variable and RTAs with technology provisions during that period as explanatory variables. In order to address endogeneity of the explanatory variables we use high-dimensional fixed effects along the following dimensions: industry-time exporter-time, importer-time, and bilateral fixed effects.

We start our econometric analysis aggregating the data across all industries so that we are left with the country-pair-time dimension. When we regress bilateral patenting flows during 1995-2019 on a dummy variable indicating whether the pair has signed an RTA. We include intra-flows of international patenting, which is possible with our data as

[1]See Martínez-Zarzoso and Chelala (2021), LaBelle and Santacreu (2021), Arregui and Martínez-Zarzoso (2022), and Santacreu (2022).

it spans a large number of patenting authorities. We find around 24% more international patenting activity for RTA members in comparison with non-members. When splitting RTAs into those with technology and non technology provisions, we find that the effect is substantially higher for agreements without technology provisions than for those with. Whereas countries belonging to RTAs with those provisions exchange knowledge around 22% more, country-pair members of RTAs without any technology provisions exchange almost twice as much (100% more) knowledge that those country pairs without RTAs.

To shed more light on these results, we leverage the industrial dimension of our patenting data and study patterns of international patenting across sectors. We first classify our industries into three groups: high tech, medium tech and low tech industries, and estimate a gravity equation of bilateral patenting flows across industries and time on our various measures of RTAs.

Finally, we study patterns of patenting flows across industries depending on the position they have on the supply chain. Specifically, we study whether countries producing in upstream sectors file more patents to countries they are connected to in downstream industries. For instance, if Taiwan specializes in the production of semiconductors that have been designed in the United States and then Taiwan supplies the semiconductors to the automobile sector in the United States, we may observe an increase in patent applications from the US automobile sector to Taiwan. We classify sectors' upstreamness using data from the World Input Output Database (WIOD) for 2014. We then create a measure of industry *compatibility* by interacting upstreamness with the supplier's import share in that sector . We extend our previous empirical model by regressing our measure of international patenting not only on RTAs with technology provisions, but also on countries' compatibility.

2 International Patenting Flows by Industry: A Dataset

We begin by constructing a new dataset of international patenting flows by industry. We use the PATSTAT Global Autumn 2021 edition to compute the number of patent applications—accounting for both the applicant and the inventor, respectively—from a country of origin (i.e., the inventor or the owner of the technology) to an application authority, at the International Patent Classification (IPC)— 4-digit IPC codes—for the period 1980-2019.[2] We then use concordance tables to transform IPC codes into industry codes—ISIC Rev 3 2-digit. The result is a dataset that contains 91 patent authorities, 213 countries of origin, 40 years, and 31 ISIC Rev 3 2-digit codes. We describe in detail how we construct this dataset next.

[2]The inventor country of residence reflects the country of origin of the innovation, whereas the applicant country of residence reflects the ownership of inventions. Not all applicants need to be inventors, as an inventor can transfer the ownership of her technology to another firm.

2.1 Construction of the Dataset

We proceed in several steps. From the raw PATSTAT data, we use SQL to pull appln_id, person_id, earliest_pat_publn_id, appln_auth, person_ctry_code, appln_filing_year, ipc_class_symbol (keeping the first 4 digits) and a count of the number of times each 4 digit IPC appears for each patent. We group across these categories giving us a raw dataset that reports, for each patent, the country where it was filed, the country of the applicant(s)/inventor(s), identifying numbers, and the IPC classes associated with each patent. Importantly, we restrict our data to application type "A", which are basic patents, and we do two separate pulls, one to get all persons who are inventors and another to get all persons/entities who are applicants.

In some cases, there may be multiple applicants/inventors from different countries on the same application. Likewise, there is often multiple technology classifications for the same patent. To avoid double counting the same patents for different countries/classifications we employ a fractional counting method for both technology class and origin country of the inventors. In other words, if one patent application has two inventors, one from Canada and one from the USA, then this patent will be counted as 0.5 patents from Canada and 0.5 patents from the USA as opposed one patent from each country. However, if a patent has four inventors, one from the US and three from Canada, then this will be counted as 0.25 patents from the USA and 0.75 from Canada. Similarly, a patent that cites multiple tech classes will be divided up across the tech classes it cites based on the number of times each class is cited.[3]

Some patent authorities are regional rather than a single country. As recognized by WIPO, these are African Regional Intellectual Property Organization (ARIPO), European Patent Office (EPO), Eurasian Patent Organization (EAPO), Gulf Cooperation Council (GCC) Patent Office, and Organisation Africaine de la Propriété Intellectuelle (OAPI).[4] Under these agreements applicants can send one application to these authorities and receive protection in all member states. However, it is not likely that all member states are attracting patents equally. We create a bilateral dataset of country-to-country patent applications that accounts for this possibility. Specifically, we employ a weighted dispersion method in which we allocate patent applications from a country to a region across the individual members of the region based on the share of direct patent applications from each origin country to each individual country of the region. For instance, suppose a hypothetical regional patent authority, UKESPDEU, that consists of the United Kingdom, Spain, and Germany. Suppose now that a applicant in the Australian Textiles industry applied for 100 patents to this UKESPDEU authority in 2021. Now suppose that the same applicant also filed patent applications directly into these countries as

[3]This differs from the data reported by the World Intellectual Property Organization (WIPO).

[4]`https://www.wipo.int/patents/en/topics/worksharing/regional-patentoffices.html`

follows: 25 patents in Germany, 10 patents in Spain and 5 patents in the United Kingdom. Out of the 40 direct patents, Germany received 62.5%, Spain received 25% and the United Kingdom received 12.5%. We use these shares to disperse out the patents filed to UKESPDEU according to these proportions, so that total patents from the Australian textile industry in 2021 would be 87.5 patents to Germany, 35 patents to Spain, and 17.5 patents to the United Kingdom, where all 140 direct and indirect patents are accounted for.

The dataset contains many missing observations, as documented by Rassenfosse, Kozak, and Seliger (2021). We use their method to impute missing values. Before imputation our dataset has over 26 million patents with a known origin and destination, after applying their method we have over 46 million. Specifically, we use the SQL codes they publish online to pull raw patent data with countries imputed based on familial findings. The basic idea of their method is similar to that of Coleman (2021). Patents are often filed in more than one country, meaning even though one country may report incomplete information on the origin of a patent, another patent authority may include more complete information for the same technology. In PATSTAT there is a wealth of information which can be used to link priority filings with subsequent filings. Thanks to this it is possible to take information off patents in the same family to impute the missing information and this is what their method does. In brief, their method can be summarized as the following, if the information is not available on the priority application, search for the information from direct equivalent patents in the same patent family. If the information can not be found on these direct equivalents, search for the information in subsequent filings in the same patent family.

However, the Rassenfosse, Kozak, and Seliger (2021) method cannot account for all blanks, rather than just drop remaining blank data, we disperse it out using data from WIPO as weights. At this stage in our dataset for every application authority, tech class, and year there is a blank country of origin with some patents attributed to it. Our goal is to assign all these remaining patents to origin countries. One option would be to assign them out based on shares of the patents which are already distributed in the data for that authority, tech class and year. The issue with this approach though is that, which countries have data and which do not is not random. Some authorities are better at reporting data and some origin countries have more robust information for the Rassenfosse, Kozak, and Seliger (2021) method to pull from. As a result, if we use these shares we may be reinforcing some bias in the data. To avoid this, we use the WIPO bilateral data as a proxy. We take the patent authorities from WIPO and compute the share of total patents for each authority that originate from each origin country for a given year. We then apply those shares to the blank data to distribute them for the respective authority and year. A necessary assumption with this approach is that the shares are assumed to be consistent across technology classes for each origin/authority relationship.

Finally, the IPC tech classes are converted into ISIC rev. 3 2-digit industries using a crosswalk that can be found in Goldschlag, Lybbert, and Zolas (2016).[5]. Our patent numbers for each tech class are multiplied by the probability weights provided and then summed across industries to give us a bilateral patenting dataset by country and industry.

Our new dataset on bilateral patent flows differs from other publicly available patent datasets, such as those compiled by the USPTO, OECD, or WIPO, along several dimensions. While USPTO only accounts for patents filed in the United States, the OECD database is more comprehensive, but only includes patents that have been filed in the United States (USPTO), the European Union (EPO), and under the Patent Cooperation Treaty (PCT). Our dataset covers many more patent offices around the world, which is especially important to capture the innovation trends observed in the past 20 years. Moreover, while WIPO includes patent applications filed in all patent offices for which data are available, it does not report these data at the industry level. Furthermore, WIPO double counts patent applications as it does not use a fractional system.

By using the full data directly from PATSTAT we are able to include patents filed with authorities besides the USPTO, EPO, and PCT included in the OECD data. We also extend our analysis to 1980-2019. Using our fractional method on its own we are able to match the data OECD provided on patents by technology class with a correlation of 96%.

A recent paper which similarly exploits the PATSTAT dataset to construct bilateral patenting flows is Coleman (2021). However, the scope of that paper is different, as Coleman (2021) is concerned with where the original innovation takes place. While their dataset is restricted to "patents of invention" which indicates a brand new invention, we are seeking to understand why people/entities apply for patents where they do; the origin of invention of a patent is secondary to who is applying for the protection in our framework.In addition, we add the industry dimension to the dataset.

2.2 Salient Features of International Patenting Flows

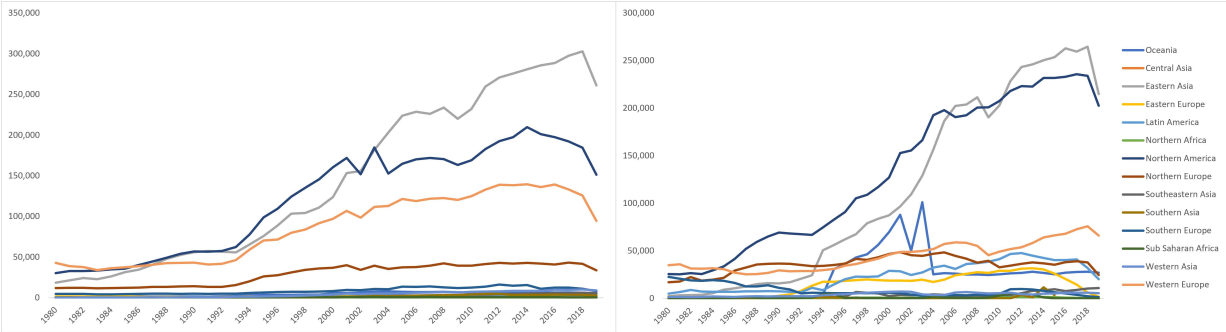
We use our dataset to document salient features of international patenting flows across industries. Among other facts, we document the rise of Asia as both origin and destination of patents applications over the past decades.

Figure 1 shows the evolution of patenting across the different regions. On the left panel we show the total amount of foreign patents filed by each region whereas on the right panel we show the amount of foreign patents received by each region.[6]. The most

[5] https://sites.google.com/site/nikolaszolas/PatentCrosswalk

[6] Foreign Patents are determined at the country jurisdiction. A patent from South Korea to Japan

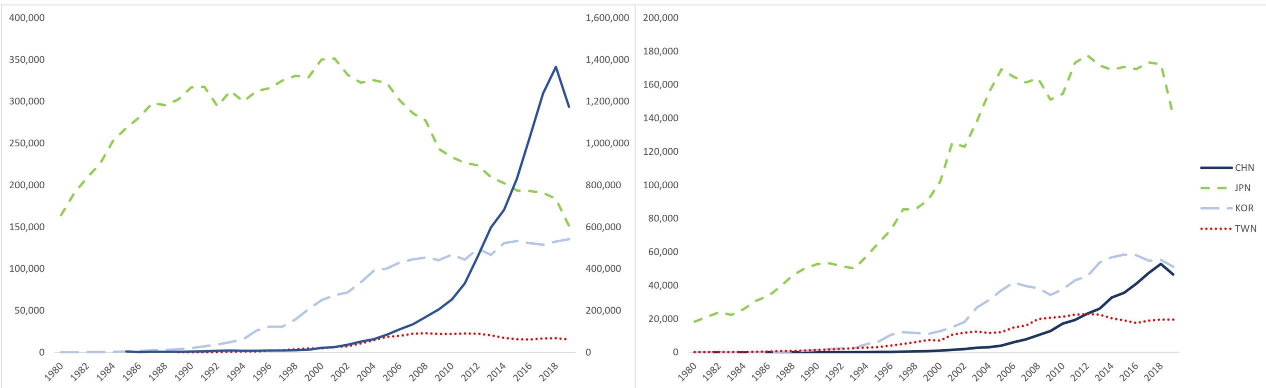
Figure 1: Patent Evolution by Region



Note: The left panel shows foreign patents filed by the different regions of the world; the right panel plots foreign patent applications received by the different regions. Caribbean was removed because of profit shifting motives affecting their data

obvious finding is Eastern Asia surpassing North America in terms of filing foreign patents back in 2003 and the margin growing since. Eastern Asia has also since passed North America as the premier destination of foreign patents as well. No other region matches Eastern Asia's rise as both filers and recipients of foreign patent applications over this time period.

Figure 2: The rise of Asia as origin of patent applications: Domestic and Abroad



Note: The left panel shows domestically filed patents (China is plotted in the right Y-axis, due to the extraordinary growth over the past two decades; the right panel plots patent applications abroad

Asian countries as origins of patent applications Next, we focus on the rise of eastern Asia and look at each country individually.[7] Figure 2 (left panel) shows the evolution of the number of domestic patent applications in 4 Asian countries: Japan, South Korea, China, and Taiwan. Japan and South Korea were traditionally innovative

occurs in the same region but it is a foreign application.

[7]Eastern Asia also includes Hong Kong and Mongolia but their is small and inconsequential so we focus on the big four here, China, Japan, South Korea, and Taiwan

countries. China and Taiwan have become new powerhouses of innovation with a growth in the number of domestic patent applications between 1995 and 2018 by a factor of 12 in Taiwan and by a factor of 139 in China. China's explosion in terms of domestic patenting is unprecedented. In fact, there is evidence that the growth can be explained by China's generous patent subsidy programs. However, on January 27, 2021, the China National Intellectual Property Administration (CNIPA) announced that these subsidies where going to be phased out by 2025. These 4 countries have also become important sources of patent applications abroad (seethe right panel of Figure 2). Japan dominates other Asian countries in the number of patent applications abroad. South Korea started rising in the 90s and it was followed by Taiwan and China. These trends show an increase in these countries' presence in terms of innovative activity. In the case of China, for instance, patent applications to the world increased by a factor of 192 from 1995 to 2019.

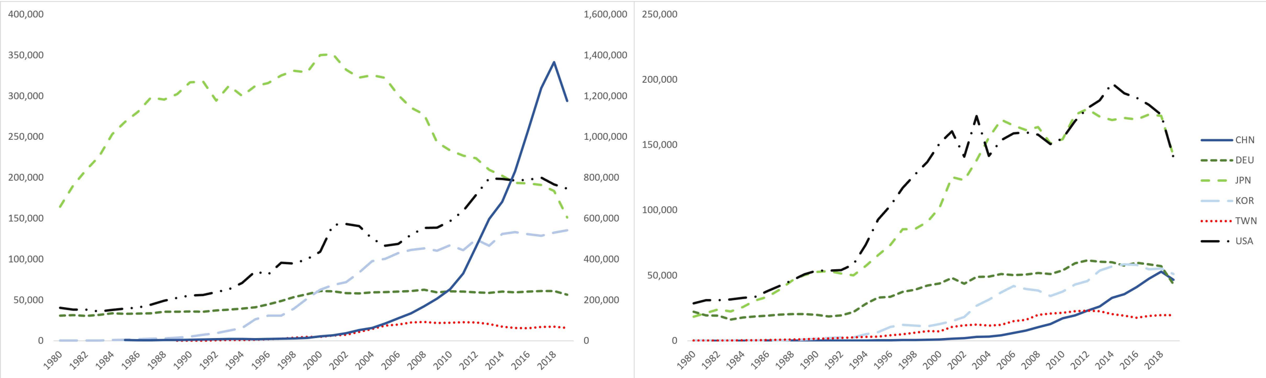
Comparing these trends with the United States and Germany, two countries that have been at the technology frontier since the 50s, we observe that the United States and Japan dominate in terms of patent applications filed abroad (right panel of Figure 3). They are followed by Germany. The Figure also shows that South Korea and China have been catching up with Germany in terms of patent applications to the world. In the case of domestic patent applications, Japan and the United States dominate (left panel of Figure 3), except for the past years in which China took over, owing to government subsidies.

Where did Asian countries filed more patent applications in the past decade? Our data shows that North America and Asia are the main destinations of patent applications by these 4 Asian countries. In the 2010s, 44% of patent applications by these 4 countries went to North America, 33% went to Eastern Asia, and 12% went to Western Europe. [8] Germany filed 33% of their foreign patents to the United States and 26% to China. The next closest destination for German patent filings was Japan with about 8%. On the other hand, the United States filed 21% of their patents in China and around 10% in each Germany and Japan in the 2010s. In terms of regions, 43% of German patents went to Eastern Asia and 34% went to North America. For the United States, 43% also went to Eastern Asia, with 22% going to Europe. In terms of all foreign patents filed in the 2010s by all countries, 36% went to Eastern Asia and 33% went to North America. Western Europe was the next largest destination with 9%. Combining all European regions together yields 19% of foreign applications received.

Asian countries as destination of patent applications Figure 4 plots the evolution of the number of patent applications filed by the world to 4 Asian countries (China,

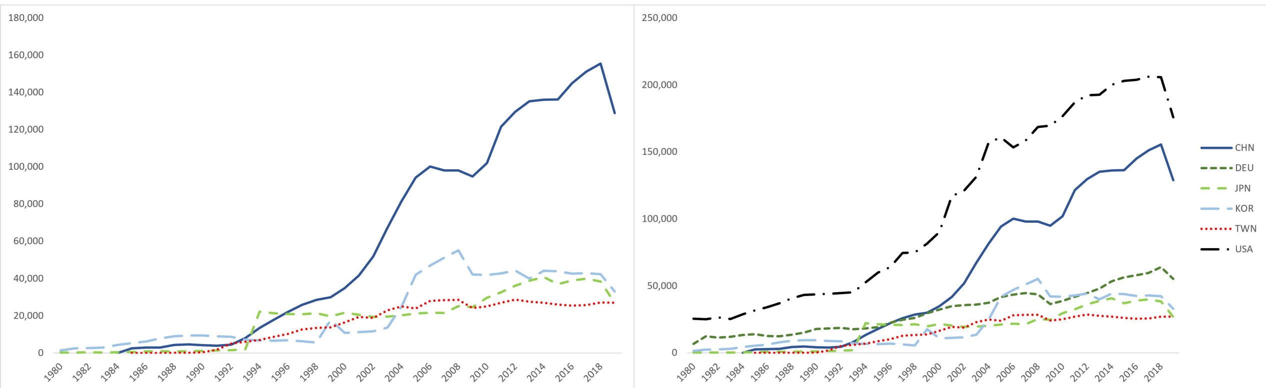
[8]Countries' domestic patents are not counted in this calculation.

Figure 3: Patent applications filed domestically and abroad



Note: The left panel shows domestically filed patents (China is plotted in the right Y-axis, due to the extraordinary growth over the past two decades; the right panel plots patent applications abroad

Figure 4: Patent applications filed from the world



Note: The left panel shows foreign patents received 4 Asian Countries; the right panel plots foreign patent applications received by 4 Asian countries and for the United States and Germany

Japan, South Korea, and Japan). China is one of the main destinations of foreign patent applications. By the mid 90s, China overtook other Asian countries and Germany as destination of foreign patent applications. Taiwan has also risen as a destination of patent applications from the world. This could be attributable to Taiwan's increasingly crucial role as the world's semiconductor, a vital upstream product, provider. While the United States is still the world leader in foreign patents received from the world, their growth path is almost mirrored by China since the 1990s. Germany, on the other hand, has a growth rate very similar to Taiwan, South Korea and Japan.

Industry Dimension In the 1980s the three most common industries for foreign patent applications in the world were Chemicals and Chemical products, 24%, Machinery and Equipment Manufacturing, 11%, and Manufacturing of Medical, Precision and Optical products, 10%. The top industries in the 2010s were, Chemical and Chemical Products, 18%, Manufacturing of Medical, Precision and Optical products, 14%, and the newcomer, Manufacturing of Accounting and Computing Machinery, 13%.

When looking at specific relationships some interesting patterns emerge. For example, 10% of the United States patents to China and 19% of their patents to Taiwan are in the radio, television and communication equipment industry, notable because of this regions importance in semiconductors. However, in United States patents to every other jurisdiction, this industry only makes us 7%. Similarly, 30% of the United States patent applications to Mexico in the 2010s were in the chemicals industry, nearly 10 percentage points higher than their total to the rest of the world.

In terms of the three most innovative regions, Eastern Asia, Western Europe and North America, Western Europe receives a greater share of patents in Machinery and Equipment, 13% compared to 8% and 7% for Eastern Asia, and North America respectively. Meanwhile Eastern Asia receives more in the Chemicals industry, 18% compared to 14% and 10% for the North America and Western Europe respectively. Eastern Asia's impressive growth as the premier patenting destination was accompanied by a slight shift in the types of patents compared to the 1980s. One-quarter of foreign patents in Eastern Asia were chemicals, which fell to 18% in the 2010s. Meanwhile, Accounting and Computing Machinery, Radio, Television and Communication Products, and Medical and optical products, increased by 6, 4, and 3 percentage points over this time period.

This indicates that, while the majority of industries are fairly stable across countries and regions, there is a regional component to the industry of the foreign patents filed. This could mean global supply chains and other factors play a role in determining not only where applicants patent, but also what they patent.

3 International Patenting: The Role of Regional Trade Agreements

We quantify the effect of various types of RTAs on international patenting flows during the period 1995-2019. The main framework for empirical analysis is a gravity model that uses international patenting as dependent variable and various RTAs as target variable. In order to address endogeneity of the target variable we follow Baier and Bergstrand (2007) and use high-dimensional fixed effects to control for unobserved heterogeneity that is specific to certain dimensions: sector-country, country-time, and bilateral.

We start by estimating a specification that does not include the industry dimension. We proceed by aggregating the data across all industries so that we are left with the country-pair-time dimension. We then estimate

$$P_{int} = \exp\left(\sum_{k=1} \text{RTA}_{int} + S_{nt} + F_{it} + fe_{in}\right) * u_{int}, \tag{1}$$

with RTA_{int} a free-trade agreement with technology provisions classified by Martínez-Zarzoso and Chelala (2021), S_{nt} exporter time, F_{it} importer time, and fe_{in} country-pair characteristics. We estimate equation (1) using both OLS and PPML methods, as recommended by Baier and Bergstrand (2007); Silva and Tenreyro (2006); Yotov et al. (2016); Zylkin (2018).

Table 1 reports summary statistics of the variables used to estimate our gravity model.

Table 1: Summary Statistics

Variable	**Mean**	**Min**	**Max**
patapp	555.52	0.00	1341381
lnpatapp	2.29	-5.59	14.11
rta	0.33	0.00	1
lndist	8.36	1.08	9.89
contig	0.06	0.00	1
comlang off	0.14	0.00	1
comcol	0.02	0.00	1
trips	0.37	0.00	1

Table 2 reports the results from regressing our data on international patenting flows on RTAs, several measures of trade costs typically used in the trade literature, and various fixed effects. The main novelty with respect to previous research is that we include intra-national patenting flows; that is, the count of domestic patent applications.[9] We can do this with our data because, in contrast with other publicly available datasets, it contains information for many patent offices around the world. We present in columns

[9]The importance of using intra-national flows when estimating gravity equations has been documented in Yotov et al. (2016) for trade flows.

(1) and (3) the estimates obtained from a log-linearized model and in columns (2) and (4) from a model in multiplicative form, with the dependent variable in levels using the PPML estimator. All models are estimated, including time-varying country-specific fixed effects (CT-FE), controlling therefore for the so-called time-variant "multilateral resistance terms" (Anderson and Van Wincoop, 2003). The table includes the results of two sets of specifications, models (1) and (2) include gravity variables, this specification allows for estimating the effects of institutional and geographical distance on technology internationalization while avoiding any omitted variable bias that results from time-varying country-specific unobservables. Models (3) and (4) additionally include also pair fixed effects to address the endogeneity of the FTA variable, as suggested by Baier and Bergstrand (2007).

Table 2: The Effect of RTAs on International Patenting Flows

VARIABLES	(1) **ols**	(2) **ppml**	(3) **ols pairfe**	(4) **pplm pairfe**
rta	-0.268***	-0.990***	0.129***	0.220***
	(0.022)	(0.107)	(0.020)	(0.044)
lndist	-0.793***	-1.298***		
	(0.012)	(0.032)	0.246	
contig	-0.373***	-2.155***		
	(0.031)	(0.081)		
comlang off	0.393***	0.725***		
	(0.020)	(0.076)		
comcol	-0.149***	-0.049		
	(0.044)	(0.106)		
trips	1.661***	4.874***	0.065	-0.131
	(0.175)	(0.584)	(0.093)	(0.138)
Constant	8.583***		2.293***	
	(0.110)		(0.023)	
FE:	it, jt	it, jt	it,jt, ij	it,jt, ij
Observations	53,951	53,951	52,901	52,901
R-squared	0.720	0.953	0.920	0.996

Notes: Robust standard errors in parentheses, cluster by pair
$***p < 0.01$, $**p < 0.05$, $*p < 0.1$

Table 3 shows the results of estimating international patenting flows on various measures of RTAs and high-dimension fixed effects, leaving the zeroes in the estimation. Columns (1) and (2), which include alternatively the TRIPS and WTO as regressors, indicate that there is around 22% more international patenting activity for RTA members in comparison with non-members. In columns (3) and (4) the results of splitting the RTA dummy into RTA tech and RTA notech indicate that the effect is substantially higher for agreements without technology provisions than for those with. Whereas countries belonging to RTAs with those provisions exchange knowledge around 20% more, country-pair members of RTAs without any technology provisions exchange almost twice as much (100% more) knowledge that those country pairs without RTAs.

Table 3: Impact of RTAs with Tech Provisions on International Patenting Flows (Zeroes)

VARIABLES	(1) patzero	(2) patzero	(3) patzero	(4) patzero
rta	0.216***	0.216***		
	(0.045)	(0.045)		
rta tech			0.202***	0.202***
			(0.046)	(0.046)
rta notech			0.684***	0.683***
			(0.171)	(0.171)
trips	-0.115		-0.118	
	(0.140)		(0.140)	
wto		-0.232*		-0.234*
		(0.132)		(0.132)
Observations	130,580	130,580	130,580	130,580
R-squared	0.996	0.996	0.996	0.996

Notes: Robust standard errors in parentheses, cluster by pair
$***p < 0.01$, $**p < 0.05$, $*p < 0.1$

Table 4 distinguishes between types of technology provisions, following the categorization of Martínez-Zarzoso and Chelala (2021). These provisions represent either a general intention to cooperate in innovation (teccop), determine a specific form of cooperation (in research and development, in technology transfer (tratech) or establish specific commitments with respect to intellectual property rights and patenting activities (patPI).

The main results in Table 4 indicate that the most relevant provisions driving the effect shown in Table 3 for RTA tech are those related to intellectual property rights and patenting activities (patPI) and to technology cooperation (teccop), as indicated in columns (2) and (3).

4 International Patenting along the Supply Chain

To be completed...

5 Conclusions

To be written...

Table 4: Impact of Different Tech Provisions on International Patenting Flows

VARIABLES	(1) patzero	(2) patzero	(3) patzero	(4) patzero
RDI	-0.0101			
	(0.053)			
patPI		0.1994***		
		(0.047)		
teccop			0.1390**	
			(0.062)	
tratech				0.1164
				(0.098)
rta notech	0.5577***	0.6814***	0.6345***	0.6152***
	(0.169)	(0.171)	(0.171)	(0.172)
wto	-0.2395*	-0.2341*	-0.2381*	-0.2479*
	(0.132)	(0.132)	(0.132)	(0.129)
Observations	130,580	130,580	130,580	130,580
R-squared	0.996	0.996	0.996	0.996

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