Do Trade Agreements Contribute to Technology Internationalization?

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Abstract

This paper investigates the effect of free trade agreements (FTAs) on technology internationalization. We estimate the effect of FTAs on domestic ownership of foreign inventions with a gravity model using a panel of 6,480 country pairs of high and middle-income countries for the period 1980-2015. The main results indicate that FTAs lead to a significant increase in technology internationalization, especially when the FTAs cover trade in goods and services. This effect increases over time considering the implementation period subsequent to the ratification and depends on the policy scope of the FTA and the economic distance between trading partners. Moreover, countries that are geographically and institutionally closer exchange more knowledge and technology and provisions on intellectual property rights add to the positive effect.

Keywords: Technology internationalization, trade agreements, knowledge flows, international technology transfers, gravity model, IPR.

JEL Codes: F13; O24; O31; O3

1. Introduction

Since the emergence of global value chains (GVC) at the end of the 20th century, innovation activities have been increasingly organized at an international level (Guellec & van Pottelsberghe de la Potterie, 2001; Picci, 2010; Baldwin, 2013). With the information technology revolution of the 1980s, decreasing communication costs led firms not only to reallocate their production lines abroad but also to seek technological resources beyond their national borders. Through this process of technology internationalization, firms have been able to exploit cost differentials, gain access to more advanced technology, and benefit from larger pools of knowledge (Lewin et al., 2009; Baldwin, 2013; World Bank, 2017).

From an aggregate perspective, this has resulted in international technology transfers (ITTs) as countries import and export ideas, expertise, and knowledge to overcome their own deficiencies and exploit their technological comparative advantage (Bathelt et al., 2004). This exchange of knowledge intensified even more drastically after the outbreak of Covid-19 in 2020, with the sharp increase in international collaborations and data sharing that emerged to obtain vaccines at speed time.

Literature from the field of international business and management has extensively studied firms' decisions to offshore their innovation activities to different geographical locations (see, for example, Gassmann & von Zedtwitz, 2002; Buckley & Ghauri, 2004; Demirbag & Glaister, 2010; Hsu et al., 2015). However, less attention has been paid to the aggregate patterns of technology internationalization that arise from firms' decisions to search for technology and innovation abroad. Using patent statistics, Guellec and van Pottelsberghe de la Potterie (2001) introduced the first aggregate indicators of technology internationalization to the literature, considering the different dimensions of cross-border ownership of inventions or international co-inventions. Building on these indicators, Picci (2010), Montobbio and Sterzi (2013), and De Prato and Nepelski (2014) provided evidence of the different factors that lead to technology internationalization between specific countries; most prominent among them were intellectual property rights and geographical and institutional distance. The results were mixed for other potential factors, such as trade, FDI and EU membership.

The present paper contributes to this strand of the literature by estimating the effect of free trade agreements (FTAs) on technology internationalization for a global sample of countries. Rather than considering trade or FDI flows, the focus is on membership in an FTA that may or may not contain technology provisions as the target variable. In this regard, our paper is closely related to Santacreu (2022), who investigates the effect of FTAs on international licensing, another important aspect of technology internationalization and to Jinji (2019), that focus on the determinants of patent citations across countries and also considers ratification of FTAs as one of the determinants. We add to this emerging literature the use of cross-country patenting applications and co-patenting as the main outcome variables.

This research also builds on a recent strand of literature that studies the effect of technology-related content of FTAs on the international exchange of goods (Maskus and Ridley, 2016; Campi and Dueñas, 2019; Martínez-Zarzoso and Chelala, 2021; LaBelle and Santacreu, 2021; Erixon et al., 2022). We borrow from it the classification of technology provisions into distinct categories and the consideration of heterogeneous effects of FTAs ratification by the level of development of the countries involved in the process of technology internationalization.

Over the years, the scope of FTAs has grown, going from mere trade liberalization to a vast range of policy areas that include the environment, the labour market, as well as investment and technology transfers (Dür et al., 2014; Hofmann et al., 2017). The empirical literature has shown that the content of trade agreements fosters ITTs through bilateral trade of goods with different technological intensities (Maskus and Ridley, 2016; Campi and Dueñas, 2019; Martínez-Zarzoso and Chelala, 2021; Erixon, 2022). These results have been heterogeneous depending on the economic level of the trading partners, the specific provisions included in an agreement and the technological intensity of the traded goods. However, the impact of the content of trade agreements on technology internationalization remains, to the best of our knowledge, understudied.

We attempt to bridge this gap in the literature by estimating a gravity model of technology internationalization using a panel of 6,480 country pairs of high and middle-income countries from 1980-2015. Patent statistics of foreign inventions owned by domestic firms are taken as a proxy for technology internationalization. Employing the Poisson Pseudo Maximum Likelihood (PPML) estimator, we estimate the effect of FTAs, their technology-related content, as well as geographical and institutional distance on the likelihood of a country owning new technologies created in another country. Methodologically, we estimate a theoretically grounded gravity model that includes proxies for the so-called multilateral resistance terms, which considers not only cross-patenting within a given pair of countries but also between a country and all its potential "technology" partners in the estimation.

The main results are twofold. First, the results indicate that FTAs have an economic and informational effect on firms' technology internationalization decisions. The first effect relates to the increase in economic interaction between trading partners after trade liberalization, which raises the likelihood of technology internationalization between countries. The second effect, in contrast, refers to a policy commitment that creates incentives for firms to internationalize their technological activities with the other member states of the agreement. Specifically, the main estimation results show that trade agreements lead to a significant increase in the technology internationalization of firms. This effect increases over time, considering the period of implementation and enforcement subsequent to the ratification of an agreement. However, the effect of FTAs on technology internationalization depends on the policy scope of the agreement and the economic distance between trading partners. Second, the results also show that geographically and institutionally closer countries exchange more technology and knowledge. This can be explained by the decreasing costs of communication and coordination associated with geographical and institutional proximity.

In addition to the new insights about the effect of FTAs on ITTs, this paper also contributes to the literature with a discussion about the theoretical framework for the analysis of technology internationalization at the aggregate level, which highlights the economic relevance of this trend.

The remainder of the paper is structured as follows. Section 2 offers a literature review of selected related studies on which the empirical analysis of this paper is built. Section 3 provides the theoretical background of this study, presents the different estimation methods and introduces the data. Section 4 details the main results from the empirical analysis of technology internationalization, and Section 5 presents a series of robustness checks that help validate the results. Finally, Section 6 offers the concluding remarks and a brief discussion about the policy implications.

2. Literature review

Technology internationalization refers to a process of innovation that is organized in different geographical locations (Guellec & van Pottelsberghe de la Potterie, 2001; Picci, 2010). It may involve, for example, geographically scattered innovation activities of firms, the use of foreign technology by national companies or international collaborations in R&D. Therefore, at the core of technology internationalization lies the exchange of knowledge and ideas across countries, resulting from firms' decisions to seek technology and innovation beyond their national borders. Against this background, understanding the influence of distance factors and, in particular, the content of FTAs on the propensity for knowledge flows across countries is linked to several branches of the literature.

On the one hand, several papers show that geographical and institutional distance act as barriers to knowledge flows since they impose constraints on the coordination and communication required in this process (Peri, 2005; Picci, 2010; Montobbio & Sterzi, 2013; De Prato & Nepelski, 2014; Jinji et al., 2019). This first strand of literature builds on the theoretical underpinnings of the gravity equation, which has been widely used in economics to analyze the determinants of bilateral trade flows. On the other hand, it also relates to literature that provides empirical evidence for the impact of technology-related content of FTAs on trade flows (Maskus & Ridley, 2016; Campi & Dueñas, 2019; Martínez-Zarzoso & Chelala, 2021, Santacreu, 2022). This second strand is based on the rationale that the content included in a trade agreement offers a policy commitment between the member states to incentivize companies to exchange technology-intensive goods with their trading partners (Büthe & Milner, 2008; Santacreu, 2022).

2.1 Barriers to knowledge flows

Introduced in economics by Tinbergen (1962), the gravity equation –derived from the gravity law of physics– suggests that bilateral interactions increase proportionally to the economic size of the partners and decrease with the physical distance between them (Head & Mayer, 2014; Yotov et al., 2016). The gravity equation was popularized in economics during the late 1990s (Krugman, 1995; Leamer & Levinsohn, 1995) and early 2000s (Anderson & van Wincoop, 2003; Eaton & Kortum, 2001, 2002). Since then, this framework has been used as a "workhorse" for studying the determinants of bilateral trade (Head & Mayer, 2014), especially due to its theoretical underpinnings based on the work of Anderson (1979), Leamer and Levinsohn (1995), Eaton and Kortum (2002) and Anderson & van Wincoop (2003). Although the gravity equation has mainly been applied to the study of the determinants of bilateral trade, its use has been extended to the analysis of other types of bilateral flows, such as migration

(Bertoli & Moraga, 2013), equity holdings in international finance (Okawa & van Wincoop, 2012) and knowledge flows (Peri, 2005; Picci, 2010; Montobbio & Sterzi, 2013; De Prato & Nepelski, 2014; Jinji et al., 2019).

Focusing on knowledge flows, Peri (2005) builds a cross-sectional gravity-like equation to explain the propensity for bilateral knowledge flows between 1975 and 1996. The author uses data on patent citations for 147 subnational regions in western Europe and North America and includes different distance factors that can be beneficial or detrimental to the bilateral exchange of knowledge. These include geographical characteristics such as common borders for regions, sub-regions and countries, joint membership in a trade bloc, common language, measures of technological development of both the cited and citing region and country-specific fixed effects. The estimation results of the gravity-like equation through a maximum likelihood estimator indicate that geographical distance is detrimental to the exchange of knowledge measured by patent citations. Furthermore, the results show that language differences also represent a barrier to the cross-regional exchange of knowledge and that joint membership in a trade bloc does not significantly impact cross-regional knowledge flows. Similarly, Jinji et al. (2019) focus on the effect of FTAs on the propensity for bilateral knowledge flows measured by patent citations. The authors estimate the average effect of FTAs on knowledge flows, as well as the impact of deeper trade agreements (agreements covering a greater number of policy areas) on the exchange of knowledge. They constructed a panel of 11,666 pairs of citing and cited regions from a set of 114 countries/regions for the period 1991 and 2007. In addition to the targeted variables, the authors also include measures of geographical distance, the patent stock of each country, a measure of technological proximity and a set of country-specific fixed effects. Estimating the model with Ordinary Least Squares (OLS) and the PPML estimator indicates that trade agreements lead to a significant increase in the exchange of knowledge between member states. However, the effect of deeper trade agreements, proxied by their content of WTO-X provisions, is insignificant in the baseline estimations. Nonetheless, when the authors divide the set of selected countries according to the socio-economic concept of Global North and Global South, the estimations confirm the positive effect of FTAs on the exchange of knowledge, irrespective of the combination of countries. Furthermore, in contrast to the estimation of the entire sample, the results reveal that the inclusion of WTO-X provisions has an additional—but minimal—positive effect for North-South and South-South combinations of countries. This effect is higher for FTAs than for CUs.

In comparison to the previous studies, Picci (2010), Montobbio and Sterzi (2013) and De Prato and Nepelski (2014) use the gravity equation to study the determinants of knowledge flows resulting from the internationalization of technology activities of firms. Using a panel of 42 countries from 1995 and 2005, Picci (2010) estimates a gravity equation of three dimensions of technology internationalization: cross-border ownership, co-ownership and co-inventions. These indicators are constructed with information about the residency of the owner(s) and inventor(s) of a patent, mapping the specific geographical location of each party. The factors included in the gravity equation are the total patent portfolio of a country, geographical characteristics such as distance between and contiguity of two countries, common language, two dummies that reflect membership in the European Union (EU) and the Euro Area (EA) and a measure of technological proximity. Applying the OLS and the PPML estimators, the author shows that technology internationalization decreases with geographical distance and is positively influenced by the presence of a common border and a common language, irrespective of the form of internationalization. Furthermore, the entry into force of the EU and EA had a positive effect on the degree of cooperation between countries.

With a narrower scope, Montobbio and Sterzi (2013) choose to focus only on the determinants of co-inventions—new technologies that have been created by inventors of at least two different countries—between developed and emerging countries. To this end, the authors use data from the USPTO[1] for eleven developing countries and seven advanced economies from 1990-2004. In addition to the frequently-used measures of geographical distance, the authors also consider differences in time zones as possible barriers to knowledge flows, arguing that they might impose constraints on firms' ability to coordinate and communicate with foreign co-inventors. The authors also include the total stock of patents and the size of the labour force in their model and consider the effect of intellectual property rights (IPR) on the extent of technology internationalization. They make the case that the strengthening of IPRs in emerging countries might increase the trust in the institutional accountability of these countries. This, in turn, could create incentives for inventors of developed economies to seek more collaborations in emerging countries, hence the relevance of this factor. Montobbio and Sterzi (2013) show, using the PPML estimator, that although geographical distance does not play a significant role in co-inventions, larger differences in time zones do. So too does cultural distance, as inventors who share a common language are more disposed to cooperate with foreign peers if they can communicate more easily. Regarding the strengthening of IPR regulations, the results indicate that the effect varies depending on the country group selected. The authors find a negative effect of IPRs for countries with higher initial levels of protection, that is, when national

[1] USPTO refers to the United States Patent and Trademark Office.

regulations were in place previous to the agreement's implementation, while a positive effect is observed for countries with weaker initial property rights. Similarly, De Prato and Nepelski (2014) also focus on co-inventions. Using patent data from the PATSTAT database, the authors estimate a gravity model of co-inventions registered in 90 patent offices worldwide from 1990-2007. This model includes measures of geographical and cultural distance, economic size, innovative potential and a measure of the position of a country in an innovation network. This last measure denotes the level of interlinkages between countries within an innovation network. Using the OLS estimator and a set of fixed effects, the authors find similar results to the previous studies. According to the estimation, geographical and cultural distance have a negative impact on the occurrence of co-inventions between countries. Furthermore, estimates for the position of a country in an innovation network indicate that the general degree of technology internationalization of a country (whether a country is at the centre of the innovation network) is a significant factor in its average number of co-inventions with other countries.

Finally, Santacreu (2022) focus on the dynamics of international technology licensing in the context of FTAs with technological provisions. She finds that FTAs with both technology and non-technology provisions positively affect bilateral royalty payments. She focuses on a sample of 41 countries from 1995 to 2012. To this literature, we add estimates of the effect of FTAs on technology internationalization using cross-country patent applications for a broader sample of countries, a more recent time frame and considering the scope of the trade agreements, focusing more specifically on technology-related provisions, as a new determining factor.

2.2 Technology content of trade agreements and their effects on trade

Although there is no empirical research that explicitly addresses the effect of FTAs and their technology-related content on the internationalization of patenting activities to the best of our knowledge, some authors have studied these effects on bilateral trade, which is considered an indirect channel of international knowledge flows and is thus related to the focus of this paper (Maskus and Ridley, 2016; Campi and Dueñas, 2019; and Martínez-Zarzoso and Chelala, 2021; Erixon et al., 2022).

Maskus and Ridley (2016) investigate whether FTAs with IPR chapters that exceed the requirements of the TRIPS[2] agreement have an additional impact on aggregate trade volumes.

[2] TRIPS refers to the agreement on Trade-Related Aspects of Intellectual Property Rights.

The authors also identify whether the effect differs depending on the development level of a country and industry. To do so, the authors use a treatment-control econometric framework in which they compare the effect of IPR-related trade agreements on exports of IPR-intensive goods versus the exports of less IPR-intensive goods. They performed this analysis for high, middle and low-income countries involving 24 agreements in 1993, 2003 and 2013. Their empirical analysis shows that IPR-related trade agreements significantly affect aggregate trade in high-technology goods and that IPR-intensive exports from middle-income countries are highly responsive to FTAs that include chapters on IPR.

Campi and Dueñas (2019) build on this research and explore whether the signing of FTAs with IPR chapters impacts bilateral trade flows for a panel of 122 countries and the period 1995-2013. The analysis is performed for low and high technology-intensive goods using matching econometrics and estimating a gravity equation.[3] The estimation results indicate that both types of FTAs (with and without IPR chapters) increase bilateral trade. Surprisingly, they show that FTAs without IPR chapters have a more pronounced effect than the other type of agreements. Indeed, when analyzing the implementation period following the entry into force of an agreement, the authors find that FTAs with IPR chapters have a higher effect over time than agreements without such provisions. Furthermore, the authors show that the effect of both types of FTAs depends on the development level of the signatory countries.

In comparison to the previous two studies, Martínez-Zarzoso and Chelala (2021) offer a broader perspective on the provisions included in trade agreements by differentiating the effect of several types of technology-related provisions according to a general intention to exchange technology and specific forms of cooperation. With this addition, the authors aim to measure the effect of FTAs depending on their technology-related content on exports of high, middle and low technology-intensity goods. To do so, the authors estimate a gravity model for 176 countries between 1995 and 2015, using the PPML estimator, finding heterogeneous results depending on the direction of trade, the economic distance of the trading partners and the type of technology content included in an agreement. According to the study's main results, FTAs that include one or more technology-related provisions generate a significantly higher trade volume than those without these provisions. Additionally, the authors find that FTAs between countries of the Global North and Global South have the greatest impact regarding trade in technology-intensive goods. More recently, Erixon et al. (2022) explored the link in EU FTAs

[3] The gravity model is estimated using an OLS estimator and without time-variant multilateral resistance terms, which could bias the results.

between IPR provisions and trade. They find a positive effect of FTAs on exports of IP-intensive goods and a marginally negative effect on exports of non-IP-intensive goods.
This paper aims to build a common framework of study based on the evidence presented above. In so doing, it seeks to contribute to the literature by offering a better understanding of the role of trade agreements in the internationalization of firms' innovative activities, highlighting the aggregate economic impact of this process of technology internationalization.

3. Theoretical Framework, Data and Empirical Specification

In this section, we first present the derivation of a gravity model, which is used to quantify the relative importance of the determinants of cross-country knowledge flows resulting from firms' internationalisation of technology. Next, we introduce and discuss the data used for the analysis and continue with the specification of the estimation method.

3.1. An empirical model of technology internationalization

The main framework is based on the model for disembodied knowledge flows proposed by Peri (2005). Let Equation (1) define the innovative output, Q_{it}, of country i at time t. Assuming that the stock of knowledge is the main input in the innovation activity of country i at time t, Q_{it} is given by:

$$Q_{it} = X_{it}(A_{it})^{\gamma}(A_{it}^{a})^{\mu} \qquad (1)$$

where X_{it} are country-specific factors that change over time t. A_{it} is the stock of knowledge in country i accumulated at time t. A_{it}^{a} is the stock of knowledge available to country i from abroad at time t. γ and μ are the respective elasticities of this Cobb-Douglas function.

If knowledge flows internationally and without restrictions, the external stock of knowledge accessible to country i could be described as $A_{it}^{a} = \sum_{j \neq i} A_{jt}$. However, assuming there may be restrictions in the diffusion of knowledge across borders, the external stock of knowledge is given by $A_{it}^{a} = \sum_{j \neq i} \phi_{ijt} A_{jt}$, where $\phi_{ijt} \in [0,1]$ is the percentage of external stock of knowledge generated in country j and accessible to country i at period t. Hence, the extent to which country i can access foreign knowledge will depend on ϕ_{ijt}. Including this term in the first equation and taking logarithms, Equation (1) results in:

$$lnQ_{it} = \ln X_{it} + \gamma \ln A_{it} + \mu \ln\left(\sum_{j \neq i} \phi_{ijt} A_{jt} \right). \qquad (2)$$

This equation states that the innovation output, $\ln Q_{it}$, in country i at time t depends on a set of time-variant country effects, $\ln X_{it}$, on the stock of national knowledge $\ln A_{it}$ and on accessible foreign knowledge $\ln(\sum_{j\neq i} \phi_{ijt} A_{jt})$. The parameter ϕ_{ijt} captures the intensity of knowledge flows and, as proposed by Peri (2005), can be interpreted as the share of knowledge generated by country j and learned by country i at time t.

In comparison to Peri (2005), we specify ϕ_{ijt} as time-variant since assuming constant access to foreign knowledge imposes a series of restrictions to international knowledge flows that are not in line with historical evidence and would constrain the correct identification of the main determinant of interest of this paper. First, decreasing trade costs and the ICT revolution of the 1980s have brought countries together and have progressively increased the frequency of international economic interactions over time. Translating this into the context of knowledge flows implies that the access to foreign knowledge has increased and not stayed constant, as proposed by Peri (2005). Second, there might be bilateral events that increase or limit the access to external knowledge flows over time. One example, and key for this empirical study, is the membership in an FTA. The idea that trade agreements enable a higher volume of knowledge flows after their entry into force requires the possibility of non-constant access to foreign knowledge and, hence, a time-variant share of ϕ.

To measure the intensity of knowledge flows for each country pair at a specific point in time, ϕ_{ijt}, we use statistics of international patents. Patent statistics provide one of the best sources of information about knowledge since, in nature, they are a compendium of ideas and innovations comprised in one legal document. Aside from the information about the innovation and application process, patents include information about the nationality or residence of the inventor and the applicant or owner of the patent. Given this set of information, a patent can be defined as "national" if it involves people or organizations of the same country and as "international" if it involves at least one inventor or owner from a different country (Guellec & van Pottelsberghe de la Potterie, 2001; OECD, 2009; Picci, 2010). The geographical difference in ownership and invention of a patent implies the internationalization of technology. Most importantly, it denotes that the ideas and information captured by the patent reflect cross-border knowledge flows either by the process of creation or ownership of the invention. Hence, using statistics of international patents allows us to map knowledge flows across countries.

Similar to Peri (2005), here $\phi_{ijt}(\tau)$ is defined as the probability that a non-obsolete idea generated by country j at time t_0 is learned by country i at time $t_1 = t_0 + \tau$ in the process of technology internationalization. That probability will depend on a series of bilateral characteristics and the time elapsed since the invention. Specifically, $\phi_{ijt}(\tau)$ is defined as:

$$\phi_{ijt}(\tau) = e^{f(i,j,t)}(1 - e^{-\beta\tau}) \quad (3)$$

where $(1 - e^{-\beta\tau})$ represents the cumulative probability function of country i learning the idea within τ years since its invention. Hence, it captures the notion that the probability of a country accessing and learning an invention of the other country grows larger as time τ passes. The factor $e^{f(i,j,t)}$, in turn, reflects the intensity of knowledge flows between country j and country i at time t, depending on a set of characteristics that act as resistance factors. This equation assumes that the resistance factors and the effect of time τ interact in a multiplicative form. Peri (2005) explains that this assumption implies that as time goes by, more ideas generated by country j will be learned by country i and that this exchange is proportional for any pair of countries.

Following the specification of the original model, in order to describe the diffusion of knowledge, the invention time interval τ is fixed for all countries and $f(i,j,t)$ is described as a function of bilateral characteristics such that:

$$\phi_{ijt} = Ce^{f(i,j,t)} = exp\,[\alpha + \delta FTA\_X_{ijt} + \beta_1 Border_{ij} + \beta_2 Language_{ij} + \beta_3 Distance_{ij} + \beta_4 Colony_{ij} + \beta_5 TRIPS_{ijt}] \quad (4)$$

where FTA_X_{ijt} represents a series of bilateral characteristics related to the membership in an FTA with/without technology-related provisions. These variables are dummies which take the value 1 if countries *i* and *j* belong to the same type of FTA and 0 otherwise. In the following section, these distinct FTA variables will be explained in more detail. $Border_{ij}$ takes the value 1 if the country pair includes contiguous countries and 0 otherwise. $Language_{ij}$ and $Colony_{ij}$ are additional dummy variables that equal 1 if the country pair shares the same language or colonial history and 0 otherwise. $Distance_{ij}$ measures the physical distance between the two countries. $TRIPS_{ijt}$ is an additional dummy variable that takes 1 if both countries comply with the TRIPS at time t and 0 otherwise. The estimates δ and ß$_1$ - ß$_5$ would show how the bilateral characteristics included in the model influence the intensity of knowledge flows between county i and country j at time t.

Due to the tacit nature of knowledge and innovation, ϕ_{ijt} cannot be directly observed. However, as pointed out before, patent statistics can be a good proxy for the generation and international transfer of new ideas. Although the advantages of using patent statistics as a measure of new knowledge have been largely documented in the literature (Griliches, 1998; Nagaoka et al., 2010), there are two possible sources of “noise” that can affect the correspondence between ideas and patents. The first one is that the propensity of patented new ideas resulting from innovation can differ across countries. The second one is that not all patents contain the same number of ideas, which makes it difficult to identify which ideas are actually transmitted across borders in the process of technology internationalization.

To account for the first problem, Peri (2005) proposes to allow the propensity to patent to differ across countries. This is denoted as $\frac{1}{\beta_j}$ and reflects an unobservable. This implies that the number of ideas generated in country j at time t, denoted as Υ_{jt}, and the number of patents granted to region j in the same period, specified as P_{jt}, follow the relation:

$$\Upsilon_{jt} = \beta_{jt} P_{jt}. \tag{5}$$

In order to solve the problem of different amounts of ideas in each patent, Peri (2005) use patent citations to proxy for the actual exchange of new knowledge between parties. In comparison, we address the second issue by using a specific dimension of internationalization of innovation activities presented in the data section, that is, *domestic ownership of foreign inventions (DOFI)*. This measure is based on the idea that domestic firms seek foreign innovation represented in a patent to use it in the domestic market and complement or overcome their own technological deficiencies. The ownership of foreign-created knowledge embodied in a patent implies that firms in the domestic market attempt to learn directly or indirectly new ideas that will allow them to achieve their economic goal. Using this measure, we assume that only new or more innovative ideas are transferred to the domestic markets by owning a patent.[4]

[4] We are aware that this assumption ignores the acquisition of patents for strategic reasons. Nonetheless, this issue lies outside the scope of this paper and is, therefore, not addressed here.

Based on Peri (2005), the following relationship is specified for patents of *DOFI* and knowledge flows:

$$c_{ijt} = \psi_{it}\Phi_{ijt}e^{\varepsilon_{ijt}}. \qquad (6)$$

where c_{ijt} represents a patent count of foreign-created innovation and granted to domestic firms (DOFI) and Φ_{ijt} is the effective number of new ideas generated in country j that are learned by country i at time t. ψ_{it} accounts for time-variant country-specific fixed effects that may alter the exchange of knowledge between two countries at a determined point in time, and $e^{\varepsilon_{ijt}}$ is a normally and independently distributed error term ε_{ijt}.

From Equations (5) and (6), it follows that:

$$\phi_{ijt} = \frac{\Phi_{ijt}}{\Upsilon_{jt}} = \frac{c_{ijt}}{\psi_{it}\beta_{jt}P_{jt}e^{\varepsilon_{ijt}}} = Ce^{f(i,j,t)} \qquad (7)$$

where ϕ_{ijt} is defined as the number of ideas learned by country i at time t, which equals Φ_{ijt} relative to the total number of ideas generated in country j (Υ_{jt}). The third term is obtained by substituting the definitions of Φ_{ijt} and Υ_{jt}. The following estimation models are specified by rearranging Equation (4) with the definitions of Equation (7):

$$c_{ijt} = exp\,[\rho_{it} + \vartheta_{jt} + \delta FTA\_X_{ijt} + b_1 Border_{ij} + b_2 Language_{ij} \qquad (8)$$
$$+ b_3 lnDistance_{ij} + b_4 Colony_{ij} + b_5 TRIPS_{ijt}] * \varepsilon_{ijt}$$

The dependent variable, c_{ijt}, is the count of patents for *DOFI* calculated for the country pair *i* and *j* with $i \neq j$, used as a proxy for the number of ideas coming from country *j* and learned by country *i* at time *t*. The bilateral number of foreign patents owned domestically depends on a series of bilateral factors that act as resistance terms, some of which are time-invariant (Border, Language, Distance)[5] and others time-variant (FTA, TRIPS) as well as on time-variant country-specific fixed effects, ρ_{it} and ϑ_{jt}. An idiosyncratic error term, ε_{ijt}, is added to the empirical model to reflect unknown uncorrelated factors with the regressors. The resulting

[5] The time invariant bilateral factors could be replaced by bilateral fixed effects θ_{ij} to account for the potential endogeneity of the the FTA variable, which is an issue in gravity models of trade.

gravity model for international knowledge[6] flows will be estimated using similar tools as those proposed by the trade literature (Head & Mayer, 2014).

In order to account for the potential endogeneity of the FTA_X variables, we also estimate a model that replaces the time-invariant gravity variables, that is, *border*, *language*, *distance* and *colony*, by pair fixed effects. In this case, the specification reads,

$$c_{ijt} = \exp\left[\rho_{it} + \vartheta_{jt} + \theta_{ij} + \gamma FTA\_X_{ijt} + \beta TRIPS_{ijt}\right] * \varepsilon_{ijt} \quad (9)$$

3.2. Data and Variables

Table 1 summarizes the data used for the main estimations of the empirical model specified in (8) and provides an overview of their descriptive statistics. The data correspond to a panel that we have compiled for 6,480 country pairs and the period 1980-2015. We start the panel's construction by selecting the largest possible country set for which aggregate data for domestic ownership of foreign inventions is available. For this, we use patent data provided by the OECD dataset *International Co-operation in Patents* (OECD, 2020).

Table 1 – Descriptive statistics

Variable	Description	No. Obs.	Mean	Std. Dev.	Min	Max
DOFI	Patent count of an invention of country *j* owned by a firm of country *i* at time *t*	233,280	2.663	29.098	0	1450
FTA	1: country pair is a member of the trade agreement at time *t* 0: otherwise	233,280	0.135	0.342	0	1
FTA_tprov	1: country pair is a member of the trade agreement with one or more technology-related provisions at time *t* 0: otherwise	233,280	0.112	0.315	0	1
FTA_zprov	1: country pair is a member of the trade agreement without any technology-related provisions at time *t* 0: otherwise	233,280	0.024	0.152	0	1
depth	Interaction variable between dummy variable FTA and depth index	233,280	0.305	1.163	0	7

[6] Although it is not directly linked to the specific relationship between trade, economic size and distance, Equation (8) has a similar structural form to the one proposed in the seminal work of Anderson and van Wincoop (2003), which introduces multilateral resistance terms and is widely used in economic literature (Head & Mayer, 2014).

Ln (distance)	Ln of geographical distance in km between country *i* and country *j*	227,520	8.480	0.970	4.088	9.892
Border	1: countries *i* and *j* are neighbours 0: otherwise	227,520	0.031	0.173	0	1
Language	1: countries *i* and *j* share official language 0: otherwise	227,520	0.087	0.282	0	1
Colony	1: countries *i* and *j* share colonial past 0: otherwise	227,520	0.022	0.148	0	1
TRIPS	1: country pair complies with the TRIPS at time *t* 0: otherwise	233,280	0.106	0.308	0	1

This dataset includes patent statistics that proxy technology internationalization across OECD and non-OECD countries and which correspond to the patterns of internationalization (based on cross-border ownership and co-inventions) proposed by Guellec and van Pottelsberghe de la Poterie (2001) and Picci (2010) for the period 1933-2018. The indicators can be selected according to the following criteria: patent office, reference data, country of reference, partner country and type of cooperation in patenting. For the patent office, we select the European Patent Office (EPO) since all patent counts in the database for other offices like the USPTO come directly or are calculated based on the reports of the EPO (OECD, 2020). By doing so, we aim at minimizing any reporting or measurement errors.

As stated before, *domestic ownership of foreign inventions* is the type of cooperation in patenting selected. In the case of the reference date, we select the priority date as it is the closest date to the actual invention process. This date refers to the first filling worldwide and is, therefore, the best approximation to the date of invention. In contrast, applications or grants of a patent generally occur between 1 and 5 years after the priority date (OECD, 2020). For the specification of countries and cooperation partners, we select all country pairs for which data is available for the period between 1980 and 2015[7].

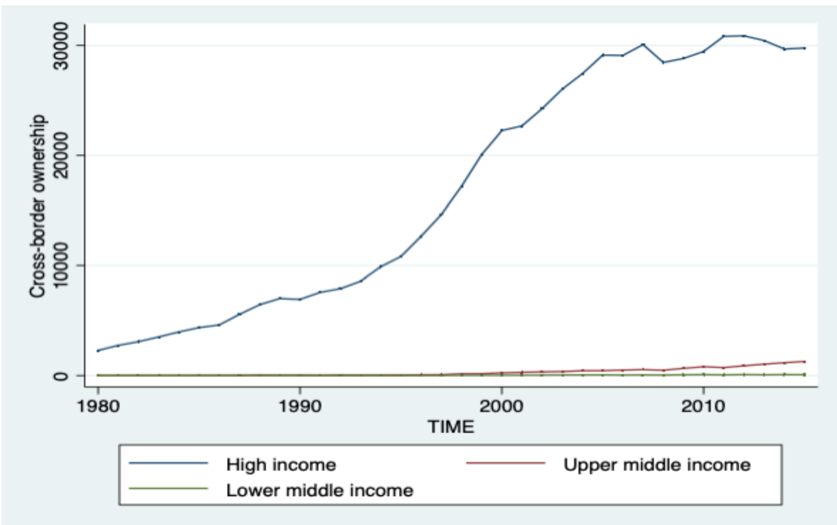
This procedure results in data for 81 countries that are paired with all other countries of the sample for 36 years. The country set includes 44 high-income countries and 37 upper and lower-middle-income countries (26 and 11, respectively). Low-income countries are excluded since their data are mostly zeroes. A detailed list of the country set with the respective income

[7] The years 2016 to 2018 are excluded since there are no values available yet for the combination of criteria chosen for this paper. The starting year is 1980, since in previous years, there is almost no variation in the data

classification can be found in the Appendix (Table A.1). The descriptive statistics of *DOFI* show that the degree of technology internationalization is highly heterogeneous across countries. The data distribution is characterized by a very low mean of 2.66 patents and a very large standard deviation of about 29 patents per country pair. The reason for this distribution is the concentration of bilateral cooperation in innovation among high-income countries. As illustrated in Figure 1, high-income countries own most of the foreign inventions in the world. Furthermore, looking in more detail at the characteristics of this distribution, the data unsurprisingly indicates that high-income countries are also the largest group of inventors since the 1980s. In particular, the United States, Germany, Switzerland and the United Kingdom have been the countries with the greatest number of domestic ownerships of foreign inventions and the largest number of domestic inventions owned by foreign firms since 1980 (see Table A.2, Appendix).

Consequently, country pairs with and among lower-middle-income countries present the lowest number of patents in the sample (see Figure 1). This translates into a high frequency of zeros (more than 80% of the entire sample) as most country pairs involve one or two middle-income countries. The high frequency of zeros is not uncommon in economic data, especially at a disaggregated level, but poses several econometric challenges which have to be acknowledged in the estimation of Equation (8) (Head & Mayer, 2014; Yotov et al., 2016). These will be discussed and addressed in the following section.

Figure 1 – Technology internationalization according to income



Note: Cross-border ownership is measured as the domestic ownership of foreign inventions. Low-income countries are not included because of a lack of data. Own illustration. **Source:** International co-operation in patents (OECD, 2020).

Building on the selection of the dependent variable, we proceed with the main independent variables of the model. For this, we use data provided by the World Bank in its dataset *Content of Deep Trade Agreements* by Hofmann et al. (2017). This dataset maps the legal content of FTAs notified at the WTO for 189 countries and the period 1958 and 2015. We selected all bilateral and regional trade agreements that correspond to the same period and set of countries chosen according to the availability of patent data. Furthermore, we extract data on technology-related provisions corresponding to each agreement as well as compliance to the TRIPS for a specific country pair at a determined point in time, which are also included in the dataset of Hofmann et al. (2017). This results in data for 179 FTAs (including enlargements of the agreements) that were active in or have entered into force since 1980. A detailed list of the FTAs included in the sample, their specific entry date into force and type can be found in the Appendix (Table A.3). For cases with more than one trade agreement at a specific point in time, we have treated all agreements of the country pair as one and determined the content of each technology-related provision by comparing each agreement and adapting the data depending on whether at least one of the agreements has had a specific provision in a specific year. With this data, we construct four dummy variables. The first one is *FTA* which takes the value of 1 if two countries are members of the same trade agreement in a specific year and 0 otherwise. With this variable, we aim at calculating the overall effect of FTAs on international cooperation in innovation activities. The second dummy is *FTA_prov* which takes the value of 1 if a country pair is a member of a trade agreement with at least one technology-related provision and 0 otherwise. The technology-related provisions included in the sample are:

- **(i)** **Intellectual Property Rights:** Implies accession to international treaties or conventions not referenced in the TRIPS.
- **(ii)** **Data Protection:** Includes exchange of information and experts and promotes joint projects between member states.
- **(iii)** **Innovation Policies:** Fosters participation in framework programs and promotion of technology transfers.
- **(iv)** **Information Society:** Relates to exchange of information, the dissemination of new technology, training as well as cooperation and exchange of information in the context of other policies.

(v) **Research and Technology:** Promotes joint research projects, exchange of researchers and the development of public-private partnerships.

Following the categorization of Martínez-Zarzoso and Chelala (2021), these provisions represent either a general intention to cooperate in innovation (provisions ii. and iii.) or determine a specific form of cooperation (provisions i. iv. and v.). With the variable *FTA_prov*, we intend to determine the effect of technology-related content of an FTA on technology internationalization. The third variable is *FTA_zprov* which takes the value of 1 if a country pair is a trade agreement member without any of the previously mentioned technology-related provisions and 0 otherwise. By including this variable in the model, we try to account for the effect of not having such provisions given a common membership in a trade agreement.

Table 2 and Figure 2 summarize the general characteristics of the FTAs included in the sample. In particular, Table 2 presents the summary statistics by type of agreement and type of provision. Overall, 79 per cent of these agreements have at least one of the previously mentioned technology-related provisions, while only 21 per cent do not include any. Of the different types of considered provisions, *IPR* is the most frequent one, followed by *information society,* which refers to the exchange of information and the dissemination of new technology, and *research and technology*, which promotes joint research projects. Hence, the data tends to include provisions that specify the form of knowledge exchange.

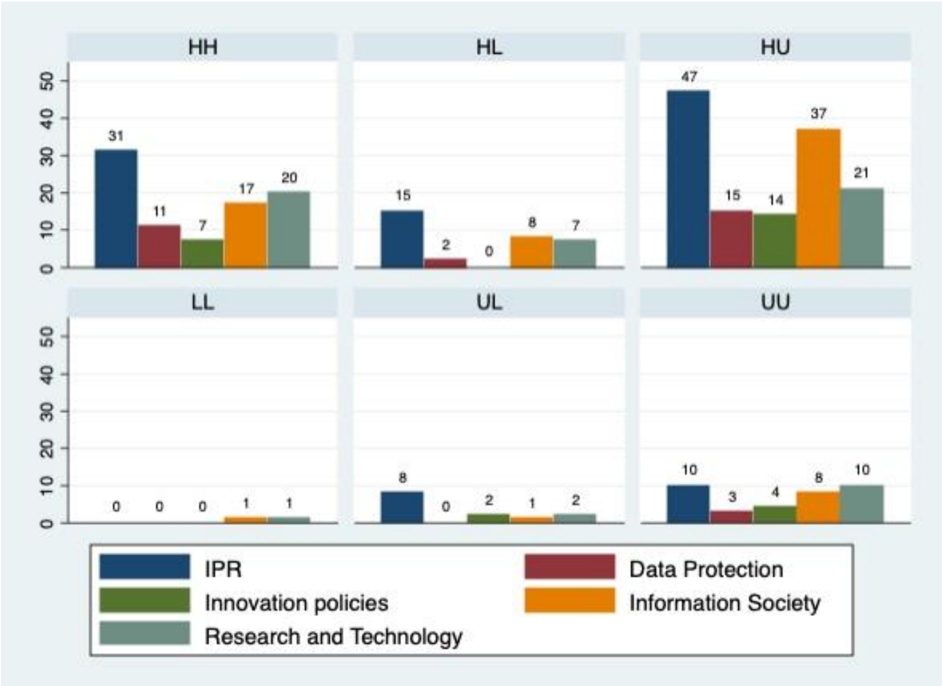
Table 2 – Free Trade Agreements and Content

Total FTAs in the sample	179
FTAs with at least one technology-related provision	141
FTAs with zero provisions	38
FTAs, according to the type of provisions	
Intellectual property rights	111
Data protection	31
Information society	72
Innovation policies	27
Research and technology	61

Note: The total number of provisions exceeds the total number of FTAs since an agreement can include more than one technology-related provision. **Source:** Hoffman et al. (2017).

Looking at the composition of the FTAs, Figure 2 shows that most of the agreements are signed between high-income and upper-middle-income countries, followed by agreements between high-income countries. Significantly less agreements are found between high-income and lower-middle-income countries as well as between middle-income countries. The content of the agreements concerning technology-related provisions also varies depending on the income level of the members in the agreement. Figure 2 also shows that IPR is the most frequently used regulation in all types of agreements. Moreover, it indicates that FTAs with or among high-income countries seem to be more comprehensive as they tend to include the five different types of technology provisions in contrast to agreements among middle-income countries, which have a narrower scope.

Figure 2. FTAs provisions according to income level of member states



Note: Bilateral and regional trade agreements in force since or after 1980, classified according to the income level of the member states and technology content. HH: FTA among high-income countries; HL: FTA among high-income and lower-middle-income countries. HU: FTA among high-income and upper-middle-income countries; UU: FTA among upper-middle-income countries; LL: FTA among lower-middle-income countries; and UL: FTA among upper and low-middle-income countries. **Source:** Hofmann et al. (2017).

In addition to the aforementioned dummy variables, we have also constructed the variable *FTA_depth*, which accounts for the depth trade agreements and is built as an interaction term between the variable *depth* extracted from Dür et al. (2014) and the dummy variable *FTA*. According to Dür et al. (2014), the depth of an FTA measures "the extent to which an agreement restricts a country's autonomy to hamper the cross-border flow of goods and services". The authors build an additive index of depth that take the values 0 to 7 and is operationalized by adding a unit if the agreement fulfils the following criteria: Is more than a partial scope agreement, has substantive provisions on services, investment, standards, public procurement, competition and/or intellectual property rights. Each category represents a higher degree of integration, determined by the scope of an agreement. By accounting for the depth of the FTAs included in the sample, we follow the suggestion of Martínez-Zarzoso and Chelala (2021). The authors explain that FTAs with technology provisions could have a greater effect on economic interactions since a greater number of provisions can lead to a deeper economic integration than shallow agreements, hence the necessity to control for depth. In fact, the correlation between the *FTA_depth* and *FTA_prov* shows a solid relationship between both variables (ρ = 0.83). All the agreements included in the sample are FTAs and hence more than a partial scope agreement. Nonetheless, only 44 per cent of the agreements have an index level of 5, 6 or 7.

Furthermore, the variables *TRIPS*, *Ln (distance)*, *Border*, *Colony* and *Language* are included in the estimations. The data for the dummy variable *TRIPS* are also obtained from Hoffman et al. (2017). This variable takes the value of 1 if both countries in a pair comply with the TRIPS at a given point in time. It is important to control for this agreement as compliance with the TRIPS has significantly affected the economic interaction between countries due to its impact on national regulatory systems (Ivus, 2010; Delgado et al., 2013). Additionally, other IPR regulations included in FTAs are expected to surpass the scope of the TRIPS, which possibly leads to a correlation between these provisions and compliance with the agreement. Specifically, since developed and less developed countries were given different periods of compliance with the TRIPS,[8] the official adherence to the agreement could have altered the content of FTAs over time and, hence, be correlated with the variable *FTA_prov* (Maskus & Ridley, 2016; Campi & Dueñas, 2019). However, the correlation coefficient of both variables shows a weak correlation (ρ = 0.40). Data for geographical and institutional distance are extracted from CEPII databases in the category *Geography*, which include geographical distance measures, colonial history and cultural characteristics, among others (Mayer & Zignago, 2011). The variables *Border*, *Colony* and *Language* are dummy variables, while the variable *Ln distance* is the logarithmic value of the simple distance between capital cities of two countries in kilometres.

[88] High-income countries implemented the TRIPS in 1995 with a couple of exceptions. Middle-income countries where grated an extended period until 2000 and low-income countries received extensions until 2013 (Maskus & Ridley, 2016).

4. Main results

Table 3 summarizes the estimation results of Equation (8) using the PPML estimator. All models are estimated, including time-varying country-specific fixed effects (CT-FE). This specification allows for estimating the effects of institutional and geographical distance on *DOFI* while avoiding any omitted variable bias that results from time-varying country-specific unobservables, controlling therefore for the so-called time-variant "multilateral resistance terms" (Anderson & van Wincoop, 2003). The table includes the results of two sets of specifications, whereas models (1) and (2) include FTA and FTA_depth variables at time t, models (3) and (4) additionally include the FTA variables at t+1 in order to test for the endogeneity of the FTA variable. Given that the coefficient of the added term is only significant at the 10% level in column (3), we can reject that FTA is endogenous in the model at the 5% level[9]. Therefore, we proceed to interpret the estimates obtained in columns (1) and (2)[10].

As reported at the bottom of Table 3 for the preferred specification, the results of the Park-type test and the auxiliary Gauss-Newton Regression (noted as GNR in Table 3) confirm the validity of the PPML for the estimation of the gravity model. On the one hand, with a p-value of 0.00, the null hypothesis of the Park-type test can be rejected at the 1 per cent level, confirming the presence of heteroskedasticity in the model and, hence, the preference of the PPML estimator over the OLS. On the other hand, with p-values of 0.184 and 0.176, the second term of the GNR, $(\ln \hat{y}_i)\sqrt{\hat{y}_i}$, is not statistically significant, which confirms the proportionality of the mean to the variance, indicating that the PPML is the best estimator of its class.

We start interpreting the estimation results with those reported in column (1). This estimation includes the variables *FTA, TRIPS, Language, Colony, Ln (distance)* and *Border*. Since Equation (8) is estimated in multiplicative form, the dependent variable of this model is *DOFI* as originally defined, that is, the internationalization of technology proxied by patent counts of domestic ownership of foreign inventions. The results indicate that all variables have the

[9] We also estimated Equation (9) with bilateral fixed effects, which has been used in the international trade literature to address the potential endogeneity of the FTA variable in gravity models for bilateral trade flows (Baier and Bergstrand, 2007). When taking these unobservable terms into consideration, the effect of *FTA* remains positive, but its magnitude drastically decreases, and the estimated coefficients lose significance and the same happens to the estimated coefficient of *TRIPS*. These models estimate the different effects keeping only the within bilateral-time variation (Baldwin & Taglioni, 2007). We anticipate that some heterogeneity issues can cause this outcome.

[10] In column (4), the coefficient of FTA_{t+1} and FTA_depth_{t+1} are, however, statistically significant; hence, we will address these endogeneity problem when considering different levels of integration latter in the paper.

expected sign, and, except for the variable *Colony,* all estimates are statistically significant at a 1 per cent level.

Table 3. FTA effect on technology internationalization: baseline model

Dependent Variable: DOFI	CT-FE	CT-FE, FTA_depth	CT-FE FTA_{t+1}	CT-FE, FTA_depth_{t+1}
Explanatory variables:	(1)	(2)	(3)	(4)
FTA	0.218***	0.328***	0.192***	0.292***
	(0.0253)	(0.0266)	(0.0298)	(0.0315)
Ln (distance)	-0.0480***	-0.00580	-0.0361***	0.00938
	(0.0119)	(0.0125)	(0.0121)	(0.0127)
Border	0.599***	0.632***	0.602***	0.638***
	(0.0233)	(0.0231)	(0.0238)	(0.0237)
Language	0.451***	0.483***	0.454***	0.490***
	(0.0232)	(0.0231)	(0.0240)	(0.0240)
Colony	-0.00289	-0.0487	-0.00283	-0.0546
	(0.0345)	(0.0344)	(0.0355)	(0.0355)
TRIPS	0.106***	0.213***	0.0773**	0.173***
	(0.0228)	(0.0251)	(0.0305)	(0.0332)
FTA_depth		-0.0833***		-0.0532***
		(0.00690)		(0.0164)
FTA (t+1)			0.0725*	0.1000**
			(0.0383)	(0.0404)
FTA_depth (t+1)				-0.0350**
				(0.0154)
Observations	124,203	124,203	119,523	119,523
R-squared	0.946	0.947	0.946	0.947
Park-type Test p-values	0.000	0.000	0.000	0.000
GNR p-values	0.142	0.135	0.089	0.005

Note: DOFI= Patent count of an invention of country *j* owned by a firm of country *i*. Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. Country-Time fixed effect refers to time-varying country-specific fixed effects. CT-FE refers to time-varying country-specific fixed effects as proxies for multilateral resistance factors.

The results show that trade agreements lead to a significant increase in domestic ownership of foreign inventions by 24.3 per cent[11]. The estimation reveals that distance factors have a detrimental effect on the internationalization of technology. For instance, the elasticity of geographical distance with respect to technology internationalization is -0.04, which is small in magnitude compared to *Border* or *Language* effects. Indeed, the estimates of *Border* imply

[11] The percentage increase in internationalization of technology attributable to the variable *FTA* is calculated by applying the exponential to the estimated value, subtracting 1, and multiplying it by 100 { $(e^{0.218} - 1) * 100 \approx 24.3\%$}.

that contiguous countries exchange technology 82 per cent more than other countries. Moreover, the estimation implies that informal institutions proxied by a shared common language positively affect the degree of internationalization of technology. Specifically, the results indicate that countries with a common language exchange around 57 per cent more technology than other countries. Furthermore, the estimate of *TRIPS* denotes a positive effect on technology exchange. The results show that the common compliance with the TRIPS increases the internationalization of technology by 11 per cent (column 1).

In previous sections, we highlighted the importance of controlling for deeper trade agreements. This is motivated by the idea that countries are more likely to interact with each other if they are members of deeper FTAs since agreements with a broader policy scope allow a larger trade liberalization (Martínez-Zarzoso & Chelala, 2021). Therefore, Model (2) includes the variable *FTA_depth*, which accounts for this relationship. The results of this model show similar effects of the different regressors on the dependent variable as in Model (1). Nonetheless, for the regressor *FTA*, the new coefficient has to be interpreted together with the coefficient of *FTA_depth*. That is, the effect is 38.8 per cent for basic FTAs and decreases by about 0.08 per cent on average for each additional provision. However, it could be that the effect of each additional provision is heterogeneous. This is examined in Table 4 below.

4.1. *The economic effect of FTAs and the role of distance factors in technology internationalization*

The results shown in Table 3 provide important insights into the determinants of the internationalization of technology. First, regarding the effect of FTAs, the results show that economic integration in the form of a trade agreement leads to a larger number of domestic firms owning inventions created in the market of their trading partners. This confirms the economic effect of FTAs on the internationalization of technology proposed in the theoretical part of this paper. The economic effect is that trade liberalization offers firms easier access to the markets of their trading partners. This, in turn, increases the probability of firms deciding to reallocate their R&D units to the partner market, seek cooperation with firms of the other member states, and, in the case of this empirical study, access technology of the other members through the ownership of patents.

The estimation results also show that geographical and institutional proximity are important determinants of technology internationalization, confirming the results of related papers like Picci (2010), Montobbio and Sterzi (2013) and De Prato and Nepelski (2014). As explained before, the costs of technology internationalization increase with geographical and institutional distance due to communication and coordination issues that restrict the exchange of knowledge and interactive learning. Of the two forms of distance, the estimation shows that institutional proximity—proxied by a common language—has a larger impact than geographical proximity on knowledge exchange if the countries are not contiguous (*Border*=0). However, contiguity seems to have a larger impact than informal institutions (proxied by colonial links). This is probably because contiguous countries are more familiar with the socio-cultural context of their neighbours, which facilitates communication and coordination irrespective of both countries sharing the same language.

Furthermore, as indicated in Table 3, common compliance with the *TRIPS* leads to a higher exchange of knowledge probably because of the worldwide institutionalization of a baseline set of regulations and protections for innovation that generated incentives for firms to create, acquire and exchange knowledge across borders. This result goes in line with other related studies that have shown that the strengthening of regulation of technology and innovation, for instance, through stronger IPR, has a particularly positive effect on the exchange of knowledge for countries with weak initial regulations (Maskus & Penubarti, 1995; Smith, 2001).

4.2. Do deeper trade agreements lead to higher technology internationalization?

One effect that has not been fully addressed yet in the literature is one of deeper trade agreements. With coefficients of -0.08 and -0.05, the estimation results of Table 3 indicate that deeper trade agreements have a significant negative effect on the internationalization of technology. These results differ from related work, which has identified a positive but small effect of deeper trade agreements on knowledge flows (Jinji et al., 2019).

In order to understand the reason for this negative relationship in the case of domestic ownership of foreign inventions, we perform an additional estimation where the effect of the variable *FTA_depth* is disaggregated into the different levels of the index constructed by Dür et al. (2014). The index takes a value between 0 and 7, according to the number of provisions included.

Table 4 – Estimation of the effect of deeper trade agreements

Dependent Variable: DOFI	
Explanatory variables:	(1)
FTA	0.287***
	(0.0354)

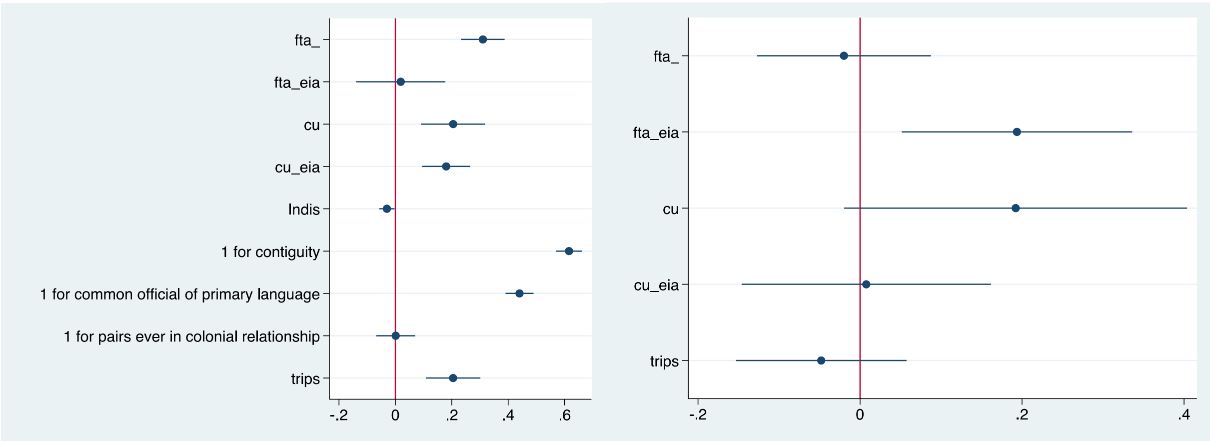
Depth 1	1.832***
	(0.524)
Depth 2	1.268***
	(0.156)
Depth 3	-0.0158
	(0.0914)
Depth 4	0.600***
	(0.0634)
Depth 5	0.117**
	(0.0525)
Depth 6	-0.428***
	(0.106)
Depth 7	-0.357***
	(0.0515)
Ln (distance)	-0.0231*
	(0.0125)
Border	0.640***
	(0.0235)
Language	0.426***
	(0.0252)
Colony	-0.00519
	(0.0359)
TRIPS	0.120***
	(0.0340)
Observations	124,203
R-squared	0.947
Park-type Test p-values	0.000
GNR p-values	0.092

Note: *DOFI* = Patent count of an invention of country *j* owned by a firm of country *i*. Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Clustered standard errors at the country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Each depth level is based on the index of Dür et al. (2014). Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

Each added provision implies more integration, as the scope of the agreement is assumed to be broader by covering more areas. The first component of the index refers to agreements that are basic (shallow) FTAs, the second one if the agreement has substantive provisions on services, the third one if it includes provisions on investment, the fourth if it has provisions on general standards, the fifth if it includes clauses on public procurement, the sixth on competition and the seventh on IPRs.

Table 4 reports the output of this estimation which confirms the results of the baseline estimation. It also indicates that FTAs with a lower number of provisions (*Depth* 1, 2, 3, 4 or 5) have a positive and generally significant effect on the internationalization of technology. On the contrary, deeper agreements (*Depth 6* and *7*) are significantly negative. These results indicate that the more complex the legal framework of an agreement, the less meaningful becomes its positive effect on the internationalization of technology. A disadvantage of the *depth index* is that it does not allow us to know which provisions, out of the 7 considered, are added into the FTAs for intermediate depths; for this reason, the interpretation is not straightforward. Hence, we consider next the traditional classification that the WTO uses, and we distinguish between FTAs with only provisions on goods (*fta_*), with provisions in goods and services (*fta_eia*), customs unions (*cu*) and economic integration agreements (*cu_eia*). The results are shown in Figure 3 below.

Figure 3. Estimated coefficients for different levels of integration



Note: the left panel shows the result for specification (8) with gravity variables and the right panel for Equation (9) with pair fixed effects.

In the left graph of Figure 3, we can see that the results for the time-invariant gravity variables stay similar when we split them by levels of integration in a classical way. In particular, sharing a border has the highest effect on DOFI, followed by sharing an official language, whereas the distance coefficient is negative and statistically significant but has a much smaller magnitude than the proxies for cultural or institutional distance. The right-hand-side graph shows the results when pair FE are added to the specification to account for the potential endogeneity of deeper RTAs. We observe that the intermediate levels of integration—for agreements that include services trade (*fta_eia*) and for CUs (*cu*)—show a significant effect (*coeff=0.22*) that is not statistically different from each other. However, the effect of basic trade agreements on goods trade and deeper CUs is close to zero and cannot be accurately estimated when pair FE are included in the specification. The estimated positive effect of TRIPS vanishes when adding pair FE, but this could be due to some heterogeneity issues, which are investigated below.

4.3 Does the technology-related content of an FTA increase its effect on the internationalization of technology?

The inclusion of different levels of integration in the estimation of specifications (8) and (9) account for the general scope of trade agreements which has grown over the last decades (Dür et al., 2014; Hofmann et al., 2017). However, looking into specific technology-related policy areas of FTAs can offer important information about the effect of this type of provision on technology internationalization. For this, we consider two different variables that aim at distinguishing the effect of FTAs depending on their technology content. The first one is *FTA_tprov* and implies the common membership in an agreement that comprises at least one technology-related provision. The second variable is *FTA_zprov*, which refers to the agreements without these provisions. Table 5 reports the corresponding estimation results. As in the baseline estimation, the effect of deeper trade agreements is controlled in the second estimation model. The theoretical section of this paper explained that technology-related provisions are expected to facilitate and foster the exchange of technology, information and knowledge through an informational effect on firms that trigger the decision to internationalize their innovation activities in or with the other member states. This cannot be confirmed by the estimation results in Table 5, perhaps because not all these provisions act in this way or due to endogeneity issues.

Table 5 – Estimation of the effect of FTAs with technology provisions

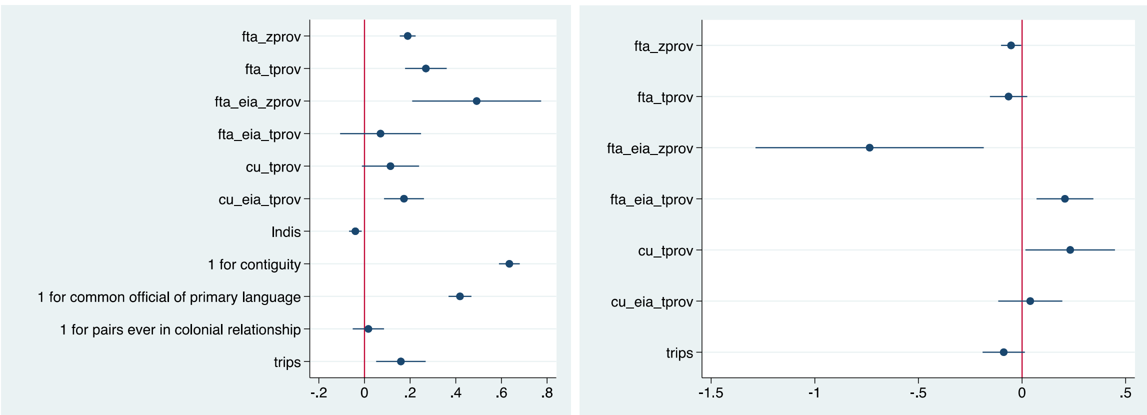
Dependent Variable: DOFI	FTA	FTA and FTA_Depth
Explanatory variables:	(1)	(2)
FTA_tprov	0.198***	0.308***
	(0.0260)	(0.0274)
FTA_zprov	0.459***	0.523***
	(0.0462)	(0.0442)
Ln (distance)	-0.0468***	-0.00611
	(0.0119)	(0.0125)
Border	0.612***	0.642***
	(0.0234)	(0.0232)
Language	0.426***	0.461***
	(0.0238)	(0.0238)
Colony	0.0181	-0.0301

	(0.0347)	(0.0347)
TRIPS	0.122***	0.224***
	(0.0233)	(0.0254)
FTA_depth		-0.0808***
		(0.00694)
No. observations	124,203	124,203
R-squared	0.946	0.947
Park-type Test p-values	0.000	0.000
GNR p-values	0.178	0.170

Note: *DOFI*= Patent count of an invention of country *j* owned by a firm of country *i*. Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Clustered standard errors at the country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

The estimation indicates that FTAs with technology-related provisions (*FTA_tprov*) lead to an increase in technology internationalization of 22 per cent. This value rises to 36 per cent when controlling for depth. However, this effect is smaller than the one estimated for FTAs without these provisions. The estimation results show that members of FTAs without technology clauses exchange knowledge 58 per cent (Model 1) and 68.7 per cent more (Model 2) than other countries. We fear that this effect is heterogeneous, varies depending on the level of integration and could be biased due to endogeneity issues. Hence, to tackle these concerns, we differentiate by the level of integration, as in the previous subsection, while distinguishing between agreements with and without technology provisions. Moreover, we also estimate model (9), which addresses endogeneity by adding bilateral FE. The results are shown in Figure 4.

Figure 4. Results by level of integration with at least one technology provisions



Note: the left panel shows the result for specification (8) with gravity variables and the right panel for Equation (9) with pair fixed effects.

We rely on the results shown in the right-hand-side graph based on specification (9) with pair FE that also should mitigate endogeneity issues (Baier and Bergstrand, 2007). It is confirmed that the intermediate levels of integration have a positive and significant effect when the agreements include at least one technology provision. The effect from *fta_eia_tprov* is not statistically different from the effect of *cu_tprov*, and the magnitude of the effect indicates that agreements in trade and services that have at least one technology provision increase trade by about 24 per cent. Interestingly, the results of FTAs in trade and services without technology provisions (*fta_eia_zprov)* show a negative and significant effect once pair FE are included. The next step consists of disentangling what the specific provisions that do have a value-added to the overall economic effect are.

4.4 What is the effect of specific technology-related provisions on the internationalization of technology?

In order to understand the outcome obtained for FTAs with technology-related provisions, we estimate the individual effect of the five technology-related provisions included in the model. Recalling the specific data provided by Hofmann et al. (2017), these provisions cover *IPR* regulations that exceed the conventions of the TRIPS, *data protection* which refers to the exchange of information and experts and promotes joint projects between member states, *innovation policies* that aim at fostering participation in framework programs and promotion of technology transfers, *information society* which relates to the exchange of information, the dissemination of new technology, training as well as cooperation and exchange of information in the context of other policies, and *research and technology* which targets the participation in joint research projects, exchange of researchers, and development of public-private-partnerships.

The results presented in column (1) of Table 6 show that the estimates for the provisions of the categories, *IPR, innovation policies* and *research and technology* have a positive sign while the estimates of *data protection* and *information society* have a negative sign and are not significant at conventional levels. The results indicate that controlling from the membership in an FTA without provisions, adding provisions of the category *IPR* and *research and technology* have an additional significantly positive effect on the internationalization of technology. Differently, the barely significant and negative coefficients of the *data protection* and *information society* provisions indicate that the inclusion of those provisions does not add much to the positive effect of FTAs on the internationalization of technology. Moreover, when including FTA_depth in column (2), it can be observed that the degree of depth of the FTA slightly varies the effect of the additional provisions on our dependent variable, but the main direction of the effects does not change. For instance, the IPR coefficient increase in magnitude, being moderated by the deepness of the agreements, which has two potential explanations. On the one hand, the estimated model comprises very heterogeneous countries. This heterogeneity can lead to mixed effects for different provisions as the context of specific country pairs may require determined policy commitments that foster the bilateral exchange of knowledge. Hence, the model cannot determine a significant average effect applicable to the entire sample. On the other hand, this output can reflect a lack of effectiveness in implementing the different provisions as each country has to translate them into national policy-making, institutional reforms and even infrastructural investments. Thus, if the provisions are not appropriately implemented, their effect on technology transfers can be virtually zero.

Table 6 – Estimation of the effect of specific technology provisions

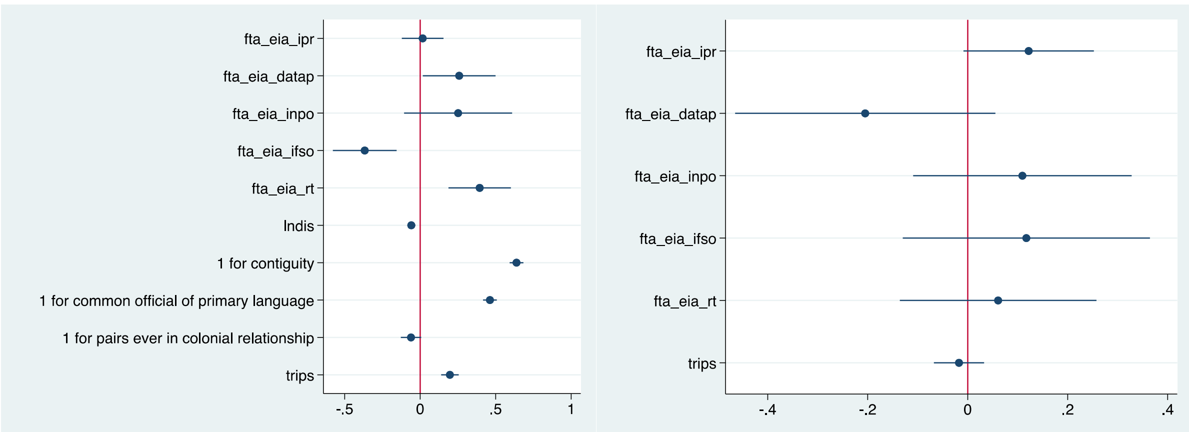
Dependent Variable: DOFI	FTA	FTA and FTA_Depth
Explanatory variables:	(1)	(2)
FTA_zprov	0.531***	0.555***
	(0.0493)	(0.0480)
IPR	0.125***	0.299***
	(0.0399)	(0.0507)
Data protection	-0.0379	-0.0847*
	(0.0499)	(0.0494)
Innovation policies	0.267*	0.309**
	(0.144)	(0.130)
Information societies	-0.125	0.00539
	(0.0829)	(0.0848)
Research & Technology	0.353***	0.218***
	(0.0405)	(0.0478)
Ln (distance)	-0.0170	-0.00592
	(0.0132)	(0.0132)
Border	0.633***	0.658***
	(0.0229)	(0.0235)
Language	0.397***	0.410***
	(0.0257)	(0.0258)
Colony	0.0205	-0.0173
	(0.0353)	(0.0356)

TRIPS	0.0179	0.106***
	(0.0314)	(0.0344)
FTA_depth		-0.0648***
		(0.00940)
No. observations	124,203	124,203
R-squared	0.945	0.946
Park-type Test p-values	0.000	0.000
GNR p-values	0.190	0.179

Note: *DOFI*= Patent count of an invention of country *j* owned by a firm of country *i*. Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Clustered standard errors at the country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

We also wonder whether there could be some endogeneity issues mainly due to omitted variable bias from differences in regulations or the quality of institutions that persist over time and affect innovation activity. Following the same reasoning as in the previous section, we estimate model (9) with pair FE that should control for these unobservable factors. We present the results for FTAs in goods and services and CUs, being those the levels of integration for which technology provision have revealed to be relevant in the previous sub-section. The results are presented in Figure 5, in which, for comparison purposes, we also present the results for the model without pair FE on the left-hand side of the figure.

Figure 5. Technology Provisions in free trade agreements for goods and services



Note: the left panel shows the result for specification (8) with gravity variables and the right panel for Equation (9) with pair fixed effects.

The graph on the right-hand side shows that only provisions that concern IPR that go beyond the minimum standards established by TRIPS show a statistically significant effect at the 10 per cent level for average levels of economic integration in the model controlling for pair FE.

4.5. Does the implementation period of an FTA influence its effect on technology internationalization?

So far, the impact of FTAs has been assumed to be an immediate effect on technology internationalization after the entry into force of an agreement. However, given that the regulations and provisions included in an FTA may require the implementation of institutional and infrastructural changes in member states, the effect of an agreement may change over time.

Table 7 – Estimation of the effect of FTAs after control of implementation period

Dependent Variable: DOFI	FTA	FTA and FTA_Depth
Explanatory variables:	(1)	(2)
FTA	0.137***	0.252***
	(0.0286)	(0.0305)
FTA (t - 5)	0.159***	0.159***
	(0.0361)	(0.0357)
FTA (t - 10)	0.0531	0.0452
	(0.0346)	(0.0341)
FTA (t - 15)	0.0384	0.0181
	(0.0381)	(0.0373)
Ln (distance)	-0.0345**	0.00294
	(0.0142)	(0.0145)
Border	0.558***	0.601***
	(0.0268)	(0.0270)
Language	0.451***	0.477***
	(0.0255)	(0.0253)
Colonial	0.0413	-0.00561
	(0.0385)	(0.0386)
TRIPS	0.0134	0.132***
	(0.0288)	(0.0319)
FTA_depth		-0.0794***
		(0.00749)
Observations	92,251	92,251
R-squared	0.947	0.948
Park-type Test p-values	0.000	0.000
GNR p-values	0.000	0.000

Note: Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. *DOFI*. FTA (t - 5), FTA (t - 10), FTA (t - 15) denote lags of the variable *FTA* of five, ten and fifteen years. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

In order to allow for this effect to vary over time, we estimate Equation (8), including various lags of the variable *FTA*. Specifically, this estimation includes three lags of five, ten and fifteen years, respectively. The variable *FTA* remains the same, and it takes the value of 1 starting on the year an FTA is ratified by two countries and for the entire duration of the agreement. The dummy variables *FTA (t - 5)*, *FTA (t - 10)*, *FTA (t - 15)*, in contrast, take the value of 1, five, ten and fifteen years after the entry into force of the FTA and remain so for the duration of the agreement. Table 7 presents these estimation results.

The estimation output points to what Yotov et al. (2016) call a phasing-in effect of FTA on the internationalization of technology. This implies that the effect of FTA increases over time. Specifically, the results show an immediate average effect of FTA on the internationalization of technology of 14.68 per cent. After five years, this effect rises by 17.23 percentage points leading to a total average effect of around 32 per cent. Between five and ten years, the increase of this effect slows down and losses significance. After ten years, the average effect vanishes. Therefore, the results indicate a non-monotonic relationship between FTAs and the international exchange of technology, a relationship also found in trade literature (see, for instance, Baier & Bergstrand, 2007).

Additionally, we also allow for the effect of the specific technology provisions to change over time. These estimation results can be found in Table A.4 in the Appendix. The results reveal that five years after the implementation of an FTA, not only the provisions related to *IPR*, *innovation policies* and *research and development* deliver a positive effect on technology internationalization, but also the clauses categorized under *information society*. Interestingly, according to the classification of Martínez-Zarzoso and Chelala (2021), these provisions determine a specific form of cooperation. More specifically, *information society* describes the promotion of ITTs through the active dissemination of knowledge and training programs. Furthermore, these provisions do not require many institutional, infrastructural or policy reforms for their implementation, for instance, IPR regulations, which may facilitate their positive effect on the exchange of knowledge.

5. Robustness Checks

Table 8 reports the main estimation results for the overall effect of *FTA* and the different measures of distance distinguished by country groups according to the level of income of the two countries involved in the internationalization of technology. Table 9 indicates the effects of FTAs depending on their technology content, and Table 10 shows the estimation results for the specific provisions. In these regressions, results from some groups containing country pairs not sharing any common characteristics cause that some coefficients cannot be estimated, which is the case for the colonial link for developing countries. Additionally, as in the previous set of regressions, the second estimation model of each group includes the variable *FTA_depth* to control for the effect of deeper trade agreements on technology internationalization.

5.1. Estimation for different groups of countries

As pointed out before, the country set selected for the analysis is highly heterogeneous, which raises the question of whether the average estimated effects for the entire sample differ by sets of countries. To account for this issue, we divide the sample into several groups depending on the economic distance of the country pairs, creating different owner/inventor combinations of countries. Recalling the definition of the dependent variable *DOFI*, "owner" refers to the country in which firms that own foreign inventions reside, while "inventor" indicates the country where the patented technology has been invented. The following set of regressions is denoted as HH, HM, MH and MM. Where H stand for high-income countries, M for middle-income countries, and the notation indicates the owner and inventor of a patent in that specific order.

The estimation results in Table 8 show that FTAs lead to a significant increase in the internationalization of technology irrespective of the country group. Moreover, the magnitude of the effect differs significantly from each other depending on the owner/inventor combination of countries. The results for the country group HH indicate that FTAs lead to a 21 per cent increase in technology internationalization if the owner and inventor of a patent come from high-income countries (column 1). In contrast, for pair of countries where the economic distance is larger, the effect of FTAs on technology internationalization is disproportionally higher in magnitude. The estimation of the group HM shows that the effect of FTAs on *DOFI* represents a 326 per cent increase in technology internationalization (column 3, coeff=1.45) if the owner of a patent comes from a high-income country and the inventor from a middle-income country. This effect is even more pronounced if the patent owner comes from a middle-income country and the inventor is from a high-income country. Specifically, the estimates of *FTA* for the group MH translate to a ninefold increase in technology internationalization (column 5). In any case, the introduction of the variable *FTA_depth* decreases the magnitude of the effect of an *FTA* for the HH country group and even more for MH, indicating that in the most comprehensive trade agreements (depth= 7), the effect is 148 %. Nevertheless, these results are only reliable for shallow FTAs, for which endogeneity issues do not apply, as found in previous sections.

Table 8. FTA effect on technology internationalization for different country groups

Dependent Variable: DOFI								
Country Groups	HH	HH	HM	HM	MH	MH	MM	MM
Expl. variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FTA	0.193***	0.322***	1.450***	1.534***	2.378***	2.805***	2.448***	2.769***
	(0.0236)	(0.0260)	(0.148)	(0.159)	(0.329)	(0.344)	(0.263)	(0.295)
Ln (distance)	-0.00437	0.0387***	-0.212***	-0.205***	-0.342***	-0.271***	-0.0358	-0.0477
	(0.0136)	(0.0136)	(0.0263)	(0.0262)	(0.0447)	(0.0417)	(0.0993)	(0.101)
Border	0.595***	0.632***	0.671***	0.730***	1.328***	1.805***	1.731***	1.652***
	(0.0235)	(0.0235)	(0.0980)	(0.121)	(0.163)	(0.151)	(0.197)	(0.200)
Language	0.436***	0.476***	0.576***	0.577***	0.217**	0.276***	0.602*	0.564*
	(0.0247)	(0.0248)	(0.0487)	(0.0485)	(0.110)	(0.107)	(0.326)	(0.318)
Colony	-0.0130	-0.0728*	0.202***	0.197***	0.803***	0.700***		
	(0.0374)	(0.0374)	(0.0538)	(0.0538)	(0.126)	(0.119)		
TRIPS	0.159***	0.285***	-1.179***	-1.103***	-1.131***	-0.487	-0.619*	-0.446
	(0.0218)	(0.0239)	(0.171)	(0.166)	(0.351)	(0.354)	(0.346)	(0.351)
FTA_depth		-0.0976***		-0.0394		-0.277***		-0.184**
		(0.00746)		(0.0284)		(0.0556)		(0.0860)
No. observations	50,233	50,233	26,070	26,070	10,930	10,930	1,497	1,497
R-squared	0.949	0.949	0.971	0.971	0.982	0.982	0.788	0.791
Park-type Test p-values	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GNR p-values	0.507	0.484	0.707	0.692	0.296	0.248	0.088	0.088

Note: Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. *DOFI*. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). HH: high-income countries. HM: high and middle-income countries. MH: middle and high-income countries. MM: middle-income countries. Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

While interpreting the magnitude of the estimated effects, it is important to keep in mind that the results represent relative changes. Given that less internationalization of technology takes place between high and middle-income countries[12] than in country pairs within the first group[13], the disproportionally large increases in technology internationalization for HM and MH represent a small absolute change in the number of international patents compared to the

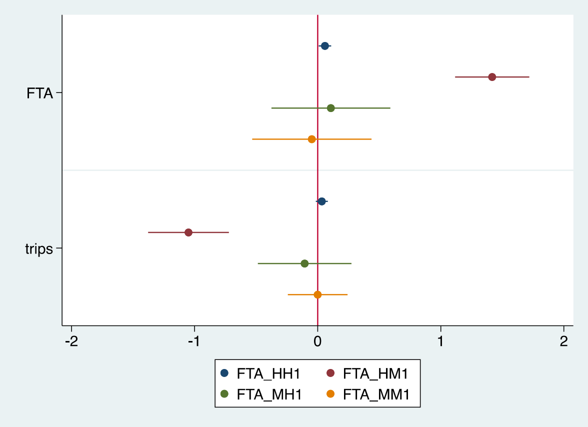
[12] Average number of *DOFI* patents for HM: 0.486 and for MH: 0.2.
[13] Average number of *DOFI* patents for HH: 8.044 patents.

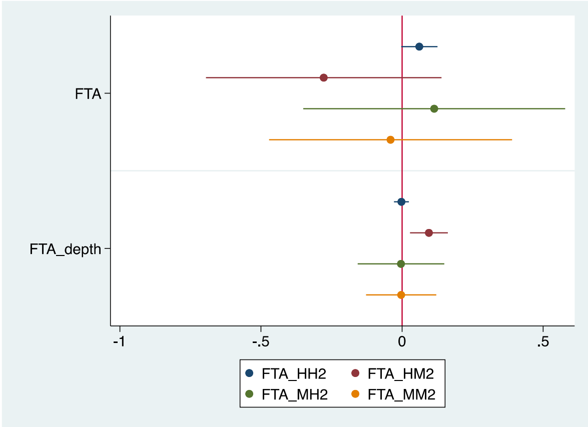
result computed for the group HH. Nonetheless, the estimated coefficients imply a higher impact of trade agreements on the internationalization of technology between high and middle-income countries and between middle-income countries than between high-income pairs.

In addition to the different effects of FTAs on technology internationalization depending on the income group, the results also show that geographical and institutional factors play a different role in the internationalization of technology depending on the economic distance between the owner and inventor of a patent. In the case of geographical factors, the results indicate that a common border positively affects *DOFI* irrespective of the country group, but that is twofold in magnitude for HM and MM combination of countries. Differently, distance seems irrelevant for the internationalization of technology between high-income countries (HH) or between middle-income countries (MM) but detrimental for country pairs with different income levels. More specifically, the results for the combination of high and middle-income countries (HM, MH) show that geographical distance is particularly negative if the owner of a patent comes from a middle-income country (MH). The *Language* estimates, which proxy for institutional proximity, show a significantly positive effect on *DOFI* irrespective of the country group but significantly higher for HM pairs. Furthermore, compared to the entire sample, the differentiation of owner/inventor according to the economic distance of the trading partners delivers significant results for common colonial history. The estimation results for the groups HM and MH imply that countries linked with a colonial past exchange more knowledge than others (22% versus 122% more for HM and MH pairs, respectively), probably because of the economic, social and cultural relationship between these countries that have remained since colonial times. Overall, geographical and institutional variables seem much more relevant for MH pairs for which the patent owner is in a middle-income country.

The average effect estimated for the FTA variable could be biased, as mentioned above, because of a potential omitted variable bias; therefore, Figure 6 presents the results accounting for pair FE, as specified in Equation (9). The FTA effect remains positive and significant only when the patent owner is in a high-income country (groups HH and HM), whereas the coefficients are imprecisely estimated for the groups MH and MM. The left-hand-side graph does not consider the depth of the FTAs, whereas the right-hand-side graph does. The coefficient of TRIPS is only shown in the left part but also included in the model estimated to obtain the right-part graph results (not shown).

Figure 6. Heterogeneity by country group in the average FTA effect, MRT and pair FE





Note: HH= owner high income, inventor high income; HM= owner high income, inventor upper or lower-middle-income MH= owner upper or lower-middle-income, inventor high income. The left-hand side graph presents results for models without FTA_depth and the right-hand side with it. The coefficients for the TRIPS variables are not shown in the right-hand side figure since they are all non-statistically significant. Based on Equation (9).

5.2 The economic effect of specific technology-related provisions by country group

In this subsection, we focus on specific provisions, and the results by the country group are presented in Table 9. The estimated coefficients for the target variable show that the effect of FTAs with technology-related provisions is smaller than the effect of agreements without this content for the groups HH and HM. Otherwise, the results of the groups MH and MM indicate that FTAs with technology-related provisions have a bigger impact (columns 5-8) on technology internationalization if the owner of a patent comes from a middle-income country (MH and MM pairs).

Table 9 – Effect of technology-related provisions on different country groups

Dependent Variable: DOFI	Groups by income level							
Country Groups	HH	HH	HM	HM	MH	MH	MM	MM
Explanatory variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FTA_zprov	0.488***	0.555***	2.158***	2.184***	1.802***	2.016***	2.110***	2.450***
	(0.0498)	(0.0473)	(0.194)	(0.195)	(0.478)	(0.426)	(0.316)	(0.322)
FTA_tprov	0.172***	0.300***	1.141***	1.196***	2.472***	3.000***	2.837***	3.301***
	(0.0242)	(0.0267)	(0.169)	(0.180)	(0.326)	(0.350)	(0.328)	(0.391)
Ln (distance)	-0.00157	0.0392***	-0.211***	-0.207***	-0.343***	-0.271***	-0.0504	-0.0662
	(0.0136)	(0.0136)	(0.0263)	(0.0262)	(0.0445)	(0.0413)	(0.0997)	(0.101)
Border	0.612***	0.645***	0.653***	0.687***	1.337***	1.846***	1.677***	1.575***
	(0.0237)	(0.0237)	(0.0946)	(0.117)	(0.165)	(0.155)	(0.203)	(0.203)
Language	0.403***	0.447***	0.573***	0.574***	0.219**	0.277***	0.640**	0.605*
	(0.0255)	(0.0258)	(0.0490)	(0.0489)	(0.110)	(0.107)	(0.326)	(0.319)
Colony	0.0161	-0.0469	0.202***	0.199***	0.804***	0.700***		
	(0.0377)	(0.0380)	(0.0535)	(0.0535)	(0.126)	(0.119)		

TRIPS	0.178***	0.295***	-0.879***	-0.840***	-1.224***	-0.645*	-0.885**	-0.732*
	(0.0223)	(0.0242)	(0.187)	(0.185)	(0.348)	(0.344)	(0.377)	(0.379)
FTA_depth		-0.0936***		-0.0229		-0.288***		-0.219**
		(0.00754)		(0.0285)		(0.0557)		(0.0913)
No. observations	50,233	50,233	26,070	26,070	10,930	10,930	1,497	1,497
R-squared	0.949	0.950	0.971	0.971	0.982	0.983	0.785	0.789
Park-type Test p-values	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GNR p-values	0.493	0.475	0.605	0.608	0.313	0.272	0.423	0.132

Note: Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. *DOFI*. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). HH: high-income countries. HM: high and middle-income countries. MH: middle and high-income countries. MM: middle-income countries. Park-type Test: null hypothesis states homoscedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. All models include time-varying origin and destination-specific fixed effects.

These results imply that technology-related content can be a positive mechanism to foster access to foreign knowledge in middle-income countries through trade policy. However, the results were less clear-cut once we added pair FE to the model. In this case, only the FTA with at least one technology-related provision positively affects the group HH that is accurately estimated. The lack of precision in the estimates for other groups could be due to the heterogeneity of the provisions included in the FTAs. Indeed, looking into the effect of the specific technology clauses included in the analysis delivers heterogeneous results for the different countries[14]. Starting with the country group HH, the estimation results reported in Table 10 show that IPR regulations that exceed the conventions of the TRIPS have a positive effect on the exchange of knowledge between high-income countries when controlling for the depth of the FTAs. In addition to this, the results show that high-income countries profit from more technology internationalization if an agreement includes provisions related to *information society* and *research & technology* (columns 1 and 2). The latter provisions, which refer to the active participation in a joint research project and the creation of public-private partnerships, are also beneficial for the HM country group (column 4). In contrast, the former, which refers to a general intention to promote technology transfer, lowers the effect of FTAs when the owner and the creator are in the HM or MH groups (columns 3-6). Moreover, *innovation policies* provisions are only statistically significant in columns (5) and (6) for MH countries and with the expected positive sign.

Table 10 – Specific technology-related provisions and different country groups

Dependent Variable: DOFI						
Country Groups	HH	HH	HM	HM	MH	MH
Explanatory variables:	(1)	(2)	(3)	(4)	(5)	(6)

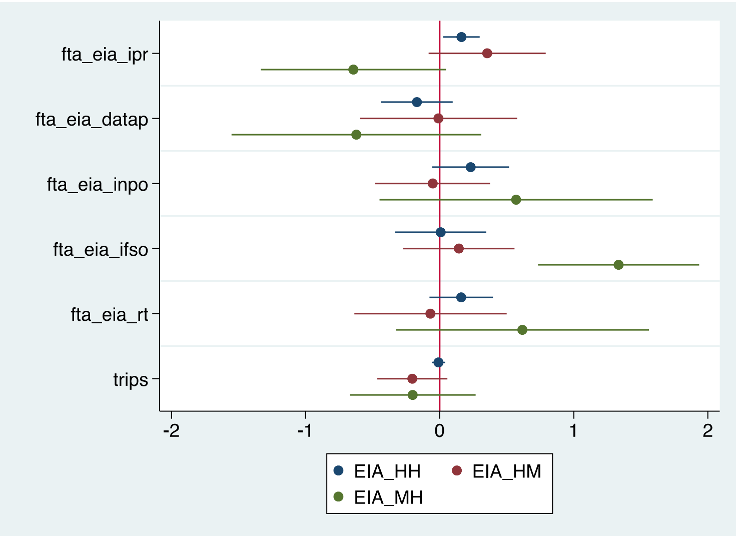
[14] In this case, we were not able to obtain separated estimates for MM countries, due to the lower number of specific technology provisions in the FTAs ratified among countries in this group (see lower part of Figure 2).

FTA-zprov	0.563***	0.583***	2.315***	2.282***	1.309***	1.326***
	(0.0542)	(0.0523)	(0.185)	(0.186)	(0.449)	(0.449)
IPR	0.00609	0.162***	1.356***	1.217***	1.762***	1.924***
	(0.0310)	(0.0414)	(0.146)	(0.160)	(0.198)	(0.224)
Data protection	-0.0103	-0.0603	0.0761	0.184	-0.167	-0.275
	(0.0480)	(0.0471)	(0.187)	(0.185)	(0.216)	(0.222)
Information society	0.804***	0.764***	-0.362**	-0.532***	-1.537***	-1.268***
	(0.127)	(0.131)	(0.182)	(0.191)	(0.407)	(0.430)
Innovation Policies	-0.212	-0.0586	-0.123	-0.156	1.661***	1.712***
	(0.135)	(0.137)	(0.139)	(0.136)	(0.203)	(0.208)
Research & Technology	0.429***	0.338***	0.172	0.276**	0.155	-0.0834
	(0.0460)	(0.0503)	(0.142)	(0.137)	(0.172)	(0.213)
Ln (distance)	0.0377***	0.0460***	-0.196***	-0.208***	-0.348***	-0.329***
	(0.0142)	(0.0143)	(0.0245)	(0.0248)	(0.0384)	(0.0396)
Border	0.642***	0.661***	0.686***	0.631***	2.158***	2.240***
	(0.0234)	(0.0239)	(0.122)	(0.127)	(0.132)	(0.135)
Language	0.387***	0.399***	0.548***	0.554***	0.257**	0.258**
	(0.0281)	(0.0283)	(0.0479)	(0.0480)	(0.108)	(0.108)
Colony	0.00574	-0.0287	0.207***	0.213***	0.775***	0.757***
	(0.0388)	(0.0392)	(0.0532)	(0.0531)	(0.127)	(0.125)
TRIPS	0.0878***	0.152***	-0.931***	-1.128***	-0.878***	-0.554**
	(0.0306)	(0.0346)	(0.139)	(0.160)	(0.219)	(0.251)
FTA_depth		-0.0562***		0.0792**		-0.113**
		(0.00982)		(0.0324)		(0.0528)
Observations	50,233	50,233	26,070	26,070	10,930	10,930
R-squared	0.950	0.950	0.972	0.972	0.984	0.985

Note: Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Dependent variable *DOFI*. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). HH: high-income countries. HM: high and middle-income countries. MH: middle and high-income countries. MM: middle-income countries. All models include time-varying origin and destination-specific fixed effects.

Regarding the second and third groups (HM, MH), the estimation indicates that IPR regulations positively affect the technology internationalization between high and middle-income countries, which is always statistically significant and shows a high magnitude. This can be related to the increased trust by firms in the institutions of middle-income countries that arise from the strengthening of IPR regulations (Maskus & Penubarti, 1995). Furthermore, the results denote that provisions of the category *innovation policies* foster the exchange of knowledge in the group of MH. In contrast, *information society* provisions seem to be detrimental to the internationalization of technology within this group. These results are relevant for shallow FTAs, given that when considering deeper FTAs, endogeneity issued could bias the estimates. For instance, once we add pair FE to the model—to address endogeneity—and estimate specification (9), the results are less informative since the coefficients are imprecisely estimated, and we cannot say much about the effects. Only considering middle levels of integration enables us to identify some effects accurately. In particular, for the FTAs in goods and services (*fta_eia*), those with a provision on *IPR* show a positive and statistically significant effect at the 5% (10%) significance level for HH (HM) country pairs, as well as those with provisions on *information society* (*ifso*) for the group MH.

Figure 7. Heterogeneity by country group and type of provision, model with MRT and pair FE



Note: HH= owner high income, inventor high income; HM= owner high income, inventor upper or lower-middle-income; MH= owner upper or lower-middle-income, inventor high income; *ipr*, *datap, inpo, ifso* and *rt*, denote that the agreement has provisions on intellectual property rights, data protection, information society and research & technology, respectively (see Table A.1 for more information on the classification). Estimations of Equation (9).

5.3 Co-inventions and international trade

Next, co-inventions were also used as an alternative dependent variable, and the results stayed similar. This dimension of internationalization implies an international exchange of knowledge through the active creation of a new technology within a globally dispersed organization of innovation activities (Bathelt et al., 2004; Caraça et al., 2009). The results in Table A.5 show the overall effect of FTAs on co-inventions. As was the case for the dependent variable *DOFI*, the significantly positive effect of FTAs can also be confirmed for co-inventions. The estimation results show that *FTA* leads to an increase in co-inventions of almost 19 per cent (Table A5, coefficient 0.173 in column 1). Comparing the results with those in Table 3, the effect of *FTA* on co-inventions is similar to the estimated effect on domestic ownership of foreign inventions, the estimates of which resulted in an increase of 24 per cent (Table 3, coefficient 0.218 in column 1).

Finally, estimations including bilateral trade as a determinant of domestic ownership of foreign inventions[15] and co-invention show that the economic interaction that results from increasing volumes of bilateral trade also has a positive effect on the decisions of firms to internationalize their technological activities with their trading partners (see Table A5, columns 3-4 show the results for co-patenting).

6. Conclusions and Policy Recommendations

This study analyzed the effect of FTAs on technology internationalization. The research question was built on the premise that trade agreements can have an economic and informational effect on the decisions of firms to internationalize their technological activities. On the one hand, FTAs increase the economic interaction between trading partners. This, in turn, raises the likelihood of firms accessing foreign innovation, reallocating their R&D units or seeking technology collaborations in the economies of their trading partners. On the other hand, the technology-related provisions included in trade agreements denote a commitment of the member states to actively promote the exchange of knowledge through improved regulation and other mechanisms like joint research projects, training and the enforcement of innovation policies. This policy commitment serves as an assurance that the economic and policy context related to the exchange of knowledge will be characterized by the conditions stipulated in the agreement. These can be either beneficial or detrimental to the internationalization decision of firms depending on their form and enforceability.

The contribution of this study to the economic literature is threefold. First, the theoretical discussion about the aggregate effect of the decisions of firms to internationalize their technological activities has highlighted the economic relevance of this trend. Second, this study has expanded the empirical evidence about the determinants of the aggregate patterns of technology internationalization, indicating that trade policy, and international policymaking in general, can influence international technology transfers. The assessment of different estimation techniques has illustrated the empirical difficulties that research in this area faces. Third, this work has provided a new perspective on the effect of the trade agreement on knowledge flows, showing that they can work either as an instrument to foster knowledge flows

[15] The results are available on request from the authors.

or as a barrier to this international trend, depending on the design of FTAs and the economic distance between the member states.

The empirical analysis is based on a gravity-like model for technology internationalization. The model is derived from the idea that the economies involved in the process of technology internationalization of firms benefit from the subsequent aggregate bilateral exchange of knowledge. Specifically, this model is built on the dimension of technology internationalization, "domestic ownerships of foreign inventions", which assumes domestic firms access and learn from foreign knowledge through the ownership of new technologies created abroad. Using the PPML estimator to estimate a gravity model using a panel dataset with more than six thousand country pairs, we obtained different effects of FTAs and their technology-related content on technology internationalization. The main estimation results of this study indicate that trade agreements lead to a significant increase in technology internationalization. This effect is non-monotonic and depends on the policy scope of a trade agreement and the economic distance between trading partners.

The first set of estimations focused on the overall effect of FTAs on the number of foreign inventions owned by domestic firms and estimated this effect with and without controls for the depth of trade agreements for the entire sample. The estimations revealed that FTAs lead to an average increase in technology internationalization of around 24 per cent. These estimations also showed that deeper trade agreements have a lower effect, probably because of the indirect effect of other policy areas like international competition on technology internationalization. Furthermore, including lags for the effect of FTA, we show that the estimated effect increases over time, reaching its maximum level 5 years after the implementation.

Given that the effect of FTAs on technology internationalization may change depending on its specific technology content and the income level of the trading partners, we performed a series of estimations that allowed the identification of differentiated results. We started by estimating the effect of FTAs depending on their technology-related content. These estimations indicated that, although FTAs have a positive effect on technology internationalization irrespective of their content, agreements without technology-related provisions have, on average, a higher effect. These results imply at first sight that, even though FTAs are a good mechanism to increase the exchange of knowledge between countries, the inclusion of technology-related provisions does not seem to add value to its overall effect. Nevertheless, estimating the effect of specific technology-related provisions for different country groups and accounting for endogeneity issues disentangles the puzzle. The results indicate that shallow trade agreements without technology-related provisions have a more pronounced effect only for country pairs where a patent owner is a firm of a high-income country. In contrast, technology-related content has a positive effect if firms from middle-income countries acquire foreign knowledge through the ownership of patents. Regarding the specific provisions, the results showed, for instance, that IPR clauses have a positive effect on the cooperation in the internationalization of technology in all country groups unequivocally. On the contrary, innovation policies are positive for pairs with middle-income countries but not so for country pairs with high-income countries as owners of the technology. Moreover, addressing endogeneity issues, although the results are less clear-cut, we can confirm the positive effect of IPR provisions in the cooperation in the internationalization of technology when a high-income country is the owner of the patent.

Furthermore, using patent statistics of co-inventions as a robustness check, that is, new technologies created by inventors of different countries, we confirmed the general effect of FTAs and their technology-related content for other dimensions of technology internationalization. Additionally, the estimation of the effect of bilateral trade on domestic ownership of foreign inventions and co-invention shows that the economic interaction that results from increasing volumes of bilateral trade also has a positive effect on the decisions of firms to internationalize their technological activities with their trading partners. Finally, within the framework of the gravity-equation, but using a theoretically justified gravity model that includes multilateral resistance proxies, we also supported the evidence of previous research regarding geographical and institutional distance. This evidence shows that countries that are geographically and institutionally close have a higher tendency to exchange knowledge with each other in the form of both technology internationalization and co-inventions. We added to the previous literature the finding that geographical and institutional variables seem to be much more relevant for country pairs, for which the owner of the patent is in a middle-income country and the inventor in a high-income one.

To conclude, it is crucial to recognize that knowledge, irrespective of its form, remains highly concentrated in high-income countries. Hence, although the results of this study denote a positive impact of trade policy on the exchange of knowledge, especially in less developed economies, the absolute impact of these policies on the diffusion of knowledge remains small. Therefore, future research and policy actors should make an effort to understand how technology-related provisions in the context of multilateral policy-making can be designed, targeted and implemented in a way that knowledge, innovation and technology are decentralized, reaching the regions of the world that need it the most.

References

Anderson, J. E. (1979). A theoretical foundation for the gravity equation. *The American Economic Review*, *69*(1), 106–116.

Anderson, J. E., & Van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *The American Economic Review*, *93*(1), 170–192.

Anderson, R. D., & Holmes, P. (2002). Competition policy and the future of the multilateral trading system. *Journal of International Economic Law*, *5*(2), 531–563.

Audretsch, D. B., & Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production. *The American Economic Review*, *86*(3), 630–640.

Aw, B. Y., Roberts, M. J., & Xu, D. Y. (2011). R&D investment, exporting, and productivity dynamics. *The American Economic Review*, *101*(4), 1312–1344.

Baier, S. L., & Bergstrand, J. H. (2007). Do free trade agreements actually increase members' international trade? *Journal of International Economics*, *71*(1), 72–95.

Baldwin, R. (2013). Trade and industrialization after globalization's second unbundling: How building and joining a supply chain are different and why it matters. In *Globalization in an age of crisis: Multilateral economic cooperation in the twenty-first century* (pp. 165–212). University of Chicago Press.

Baldwin, R., & Taglioni, D. (2007). Trade effects of the euro: A comparison of estimators. *Journal of Economic Integration*, 780–818.

Bathelt, H., Malmberg, A., & Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, *28*(1), 31–56.

Becker, W., & Dietz, J. (2004). R&D cooperation and innovation activities of firms—Evidence for the German manufacturing industry. *Research Policy*, *33*(2), 209–223.

Bertoli, S., & Moraga, J. F.-H. (2013). Multilateral resistance to migration. *Journal of Development Economics*, *102*, 79–100.

Blind, K., Cremers, K., & Mueller, E. (2009). The influence of strategic patenting on companies' patent portfolios. *Research Policy*, *38*(2), 428–436.

Bloom, N., Draca, M., & Van Reenen, J. (2016). Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity. *The Review of Economic Studies*, *83*(1), 87–117.

Boschma, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies*, *39*(1), 61–74.

Branstetter, L. (2006). Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's FDI in the United States. *Journal of International Economics*, *68*(2), 325–344.

Buckley, P. J., & Ghauri, P. N. (2004). Globalisation, economic geography and the strategy of multinational enterprises. *Journal of International Business Studies*, *35*(2), 81–98.

Bustos, P. (2011). Trade liberalization, exports, and technology upgrading: Evidence on the impact of MERCOSUR on Argentinian firms. *The American Economic Review*, *101*(1), 304–40.

Büthe, T., & Milner, H. V. (2008). The politics of foreign direct investment into developing countries: Increasing FDI through international trade agreements? *American Journal of Political Science*, *52*(4), 741–762.

Campi, M., & Dueñas, M. (2019). Intellectual property rights, trade agreements, and international trade. *Research Policy*, *48*(3), 531–545.

Caraça, J., Lundvall, B.-Å., & Mendonça, S. (2009). The changing role of science in the innovation process: From Queen to Cinderella? *Technological Forecasting and Social Change*, *76*(6), 861–867.

Castellani, D., Jimenez, A., & Zanfei, A. (2013). How remote are R&D labs? Distance factors and international innovative activities. *Journal of International Business Studies*, *44*(7), 649–675.
Coe, D. T., & Helpman, E. (1995). International r&d spillovers. *European Economic Review*, *39*(5), 859–887.
Correia, S. (2018). REGHDFE: Stata module to perform linear or instrumental-variable regression absorbing any number of high-dimensional fixed effects. In *Statistical Software Components*. Boston College Department of Economics. Available at: https://ideas.repec.org/c/boc/bocode/s457874.html
Dachs, B., & Pyka, A. (2010). What drives the internationalisation of innovation? Evidence from European patent data. *Economics of Innovation and New Technology*, *19*(1), 71–86.
De Prato, G., & Nepelski, D. (2014). Global technological collaboration network: Network analysis of international co-inventions. *The Journal of Technology Transfer*, *39*(3), 358–375.
Delgado, M., Kyle, M., & McGahan, A. M. (2013). Intellectual property protection and the geography of trade. *The Journal of Industrial Economics*, *61*(3), 733–762.
Demirbag, M., & Glaister, K. W. (2010). Factors determining offshore location choice for R&D projects: A comparative study of developed and emerging regions. *Journal of Management Studies*, *47*(8), 1534–1560.
Dür, A., Baccini, L., & Elsig, M. (2014). The design of international trade agreements: Introducing a new dataset. *The Review of International Organizations*, *9*(3), 353–375.
Eaton, J., & Kortum, S. (2001). Trade in capital goods. *European Economic Review*, *45*(7), 1195–1235.
Eaton, J., & Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, *70*(5), 1741–1779.
Eaton, J., & Tamura, A. (1994). Bilateralism and regionalism in Japanese and US trade and direct foreign investment patterns. *Journal of the Japanese and International Economics. 8(4)*, 478-510.
Erixon, F., Guinea, O., Lamprecht, P. and Van der marel, E. (2022). The benefits of intellectual property rights in the EU free trade agreements: Full report. ECIPE Occasional Paper Nº 01/2022, European Centre for International Political Economy, Brussels.
Fischer, M. M., Scherngell, T., & Reismann, M. (2009). Knowledge spillovers and total factor productivity: Evidence using a spatial panel data model. *Geographical Analysis*, *41*(2), 204–220.
Freeman, C. (2002). Continental, national and sub-national innovation systems—Complementarity and economic growth. *Research Policy*, *31*(2), 191–211.
Gassman, O., & von Zedtwizt, M. (2002). Market versus technology drive in R&D internationalization: Four different patterns of managing research and development. *Research Policy*, *31*(4), 569–588.
Griliches, Z. (1998). Patent statistics as economic indicators: A survey. In *R&D and productivity: The econometric evidence* (pp. 287–343). University of Chicago Press.
Grossman, G. M., & Helpman, E. (1991). Trade, knowledge spillovers, and growth. *European Economic Review*, *35*(2–3), 517–526.
Guellec, D., & van Pottelsberghe de la Potterie, B. (2001). The internationalisation of technology analysed with patent data. *Research Policy*, *30*(8), 1253–1266.
Hafner-Burton, E. M., & Tsutsui, K. (2005). Human rights in a globalizing world: The paradox of empty promises. *American Journal of Sociology*, *110*(5), 1373–1411.
Hall, B. H., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of Economics*, 16–38.
Head, K., & Mayer, T. (2014). Gravity equations: Workhorse, toolkit, and cookbook. In *Handbook of international economics* (Vol. 4, pp. 131–195). Elsevier.

Hofmann, C., Osnago, A., & Ruta, M. (2017). *Horizontal depth: A new database on the content of preferential trade agreements*. The World Bank.
Hsu, C.-W., Lien, Y.-C., & Chen, H. (2015). R&D internationalization and innovation performance. *International Business Review*, *24*(2), 187–195.
Ivus, O. (2010). Do stronger patent rights raise high-tech exports to the developing world? *Journal of International Economics*, *81*(1), 38–47.
Jaffe, A. B., Trajtenberg, M., & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, *108*(3), 577–598.
Jinji, N., Zhang, X., & Haruna, S. (2019). Do deeper regional trade agreements enhance international technology spillovers? *The World Economy*, *42*(8), 2326–2363.
Keller, W. (2010). International trade, foreign direct investment, and technology spillovers. In *Handbook of the Economics of Innovation* (Vol. 2, pp. 793–829). Elsevier.
Krugman, P. (1995). Increasing returns, imperfect competition and the positive theory of international trade. *Handbook of International Economics*, *3*, 1243–1277.
Krugman, P. R. (1991). *Geography and trade*. MIT press.
LaBelle, J., & Santacreu, A. M. (2021). Technology Transfer and Regional Trade Agreements. Economic Synopses 23. Federal Reserve Bank of St. Louis. *Available at SSRN 3941632*.
Larch, M., Wanner, J., Yotov, Y. V., & Zylkin, T. (2019). Currency unions and trade: A PPML re-assessment with high-dimensional fixed effects. *Oxford Bulletin of Economics and Statistics*, *81*(3), 487–510.
Leamer, E., & Levinsohn, J. (1995). *International Trade theory: The Evidence. Handbook of International Economics, V 3. G. Grossman and K. Rogoff, eds*.
Lewin, A. Y., Massini, S., & Peeters, C. (2009). Why are companies offshoring innovation? The emerging global race for talent. *Journal of International Business Studies*, *40*(6), 901–925.
Manning, W. G., & Mullahy, J. (2001). Estimating log models: To transform or not to transform? *Journal of Health Economics*, *20*(4), 461–494.
Mansfield, E. D., & Reinhardt, E. (2008). International institutions and the volatility of international trade. *International Organization*, *62*(4), 621–652.
Martínez-Zarzoso, I., & Chelala. S. (2021). Trade Agreements and International Technology Transfer. *Review of World Economics*. Forthcoming.
Maskus, K. E., & Penubarti, M. (1995). How trade-related are intellectual property rights? *Journal of International Economics*, *39*(3–4), 227–248.
Maskus, K. E., & Ridley, W. (2016). Intellectual property-related preferential trade agreements and the composition of trade. *Robert Schuman Centre for Advanced Studies Research Paper*, *2016/35*.
Mayer, T., & Zignago, S. (2011). *Notes on CEPII's distances measures: The GeoDist database*.
Montobbio, F., & Sterzi, V. (2013). The globalization of technology in emerging markets: A gravity model on the determinants of international patent collaborations. *World Development*, *44*, 281–299.
Nagaoka, S., Motohashi, K., & Goto, A. (2010). Patent statistics as an innovation indicator. In *Handbook of the Economics of Innovation* (Vol. 2, pp. 1083–1127). Elsevier.
Nieto, M. J., & Rodríguez, A. (2011). Offshoring of R&D: Looking abroad to improve innovation performance. *Journal of International Business Studies*, *42*(3), 345–361.
OECD. (2009). *OECD Patent Statistics Manual*. OECD Publishing.
OECD. (2020). *Indicators of international co-operation* [Doi:https://doi.org/10.1787/data-00507-en]. https://www.oecd-ilibrary.org/content/data/data-00507-en
Okawa, Y., & Van Wincoop, E. (2012). Gravity in international finance. *Journal of International Economics*, *87*(2), 205–215.

Pavcnik, N. (2002). Trade liberalization, exit, and productivity improvements: Evidence from Chilean plants. *The Review of Economic Studies*, *69*(1), 245–276.
Peeters, C., & van Pottelsberghe de la Potterie, B. (2006). Innovation strategy and the patenting behavior of firms. *Journal of Evolutionary Economics*, *16*(1–2), 109–135.
Peri, G. (2005). Determinants of knowledge flows and their effect on innovation. *Review of Economics and Statistics*, *87*(2), 308–322.
Picci, L. (2010). The internationalization of inventive activity: A gravity model using patent data. *Research Policy, 39*(8), 1070–1081.
Rickard, S. J., & Kono, D. Y. (2014). Think globally, buy locally: International agreements and government procurement. *The Review of International Organizations*, *9*(3), 333–352.
Rivera-Batiz, L. A., & Romer, P. M. (1991). International trade with endogenous technological change. *European Economic Review*, *35*(4), 971–1001.
Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, *98*(5, Part 2), 71–102.
Saggi, K. (2002). Trade, foreign direct investment, and international technology transfer: A survey. *The World Bank Research Observer*, *17*(2), 191–235.
Santacreu, A.M. (2022). Dynamic Gains from Trade Agreements with Intellectual Property Provisions. Federal Reserve Bank of St. Louis. Mimeo.
Santos Silva, J, & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics, 88*(4), 641–658.
Santos Silva, J, & Tenreyro, S. (2011). Further simulation evidence on the performance of the Poisson pseudo-maximum likelihood estimator. *Economics Letters*, *112*(2), 220–222.
Smith, P. J. (2001). How do foreign patent rights affect US exports, affiliate sales, and licenses? *Journal of International Economics*, *55*(2), 411–439.
Tinbergen, J. (1962). *Suggestions for an international economic policy*. Twentieth Century Fund. New-York.
World Bank. (2017). *Measuring and analyzing the impact of GVCs on economic development.* World Bank Group. Washington, D.C.
Yotov, Y. V., Piermartini, R., Monteiro, J.-A., & Larch, M. (2016). *An advanced guide to trade policy analysis: The structural gravity model*. World Trade Organization Geneva.

APPENDIX

Table A.1. Country list and income classification

Country	Income classification	Country	Income classification
Algeria	Upper middle income	Latvia	High income
Andorra	High income	Lebanon	Upper middle income
Argentina	Upper middle income	Liechtenstein	High income
Armenia	Upper middle income	Lithuania	High income
Australia	High income	Luxembourg	High income
Austria	High income	Malaysia	Upper middle income
Belarus	Upper middle income	Malta	High income
Belgium	High income	Mexico	Upper middle income
Bosnia and Herzegovina	Upper middle income	Moldova	Lower middle income
Brazil	Upper middle income	Morocco	Lower middle income
Bulgaria	Upper middle income	Netherlands	High income
Canada	High income	New Zealand	High income
Chile	High income	Norway	High income
China	Upper middle income	Pakistan	Lower middle income
Colombia	Upper middle income	Panama	High income
Costa Rica	Upper middle income	Peru	Upper middle income
Cyprus	High income	Philippines	Lower middle income
Czech Republic	High income	Poland	High income
Denmark	High income	Portugal	High income
Ecuador	Upper middle income	Romania	Upper middle income
Egypt	Lower middle income	Russian Federation	Upper middle income
El Salvador	Lower middle income	Saudi Arabia	High income
Estonia	High income	Singapore	High income
Finland	High income	Slovak Republic	High income
France	High income	Slovenia	High income
Georgia	Upper middle income	South Africa	Upper middle income
Germany	High income	Spain	High income
Greece	High income	Sri Lanka	Upper middle income
Guatemala	Upper middle income	Sweden	High income
Hong Kong	High income	Switzerland	High income
Hungary	High income	Thailand	Upper middle income
Iceland	High income	Tunisia	Lower middle income
India	Lower middle income	Turkey	Upper middle income
Indonesia	Lower middle income	Ukraine	Lower middle income
Ireland	High income	United Arab Emirates	High income
Israel	High income	United Kingdom	High income
Italy	High income	United States	High income
Jamaica	Upper middle income	Uruguay	High income
Japan	High income		
Jordan	Upper middle income		
Kazakhstan	Upper middle income		
Kenya	Lower middle income		
South Korea	High income		

Note: 81 countries. Income groups correspond to the classification of the World Bank in 2019.

Table A.2. Domestic ownership of foreign inventions (Top 5 country pairs)

Year	Owner	Inventor	Count	Year	Owner	Inventor	Count
1980	UK	US	99	2000	US	France	659
	Germany	United	137		Switzerland	Germany	686
	US	UK	139		Germany	US	901
	Switzerland	Germany	145		US	Germany	1143
	US	Germany	161		US	UK	1450
1985	Netherlands	UK	153	2005	Switzerland	US	896
	Germany	US	178		Germany	US	1001
	Netherlands	Germany	217		Switzerland	Germany	1038
	Switzerland	Germany	233		US	UK	1225
	US	UK	261		US	Germany	1426
1990	Germany	US	258	2010	Germany	US	833
	Switzerland	Germany	279		Switzerland	US	839
	UK	US	279		US	UK	967
	US	Germany	324		Switzerland	Germany	1004
	US	UK	423		US	Germany	1043
1995	US	Japan	360	2015	US	China	696
	Switzerland	Germany	376		Switzerland	Germany	964
	Germany	US	397		US	UK	965
	US	Germany	531		Germany	US	997
	US	UK	781		US	Germany	1067

Note: Number of international patents. Own calculation. **Source:** OECD (2020).

Table A.3. List of agreements

Agreement	Entry into force	Type
ASEAN free trade area	1992	FTA
ASEAN-Australia-New Zealand	2010	FTA & EIA
ASEAN-India	2010	FTA & EIA
ASEAN-Korea	2010	FTA & EIA
Armenia - Kazakhstan	2001	FTA
Armenia - Moldova	1995	FTA
Armenia - Russian Federation	1993	FTA
Armenia - Ukraine	1996	FTA
Australia-New Zealand (ANZCERTA)	1983	FTA & EIA
Australia-Singapore	2003	FTA & EIA
Australia-Thailand	2005	FTA & EIA
CAFTA-DR	2006	FTA & EIA
CAN	1988	CU
CEFTA	2007	FTA
CEZ	2004	FTA
CIS	1994	FTA
COMESA	1994	CU
Canada - Chile	1997	FTA & EIA
Canada - Colombia	2011	FTA & EIA
Canada - Costa Rica	2002	FTA
Canada - Israel	1997	FTA
Canada - Jordan	2012	FTA
Canada - Panama	2013	FTA & EIA
Canada - Rep. of Korea	2015	FTA & EIA
Canada-EFTA	2009	FTA
Canada-Peru	2009	FTA & EIA
Central American Common Market (CACM)	1961	CU
Chile - Colombia	2009	FTA & EIA
Chile - Central America	2002	FTA & EIA
Chile - Malaysia	2012	FTA
Chile - Mexico	1999	FTA & EIA
Chile-Australia	2009	FTA & EIA
Chile-China	2006	FTA & EIA
Chile-Japan	2007	FTA & EIA
Chile-Korea	2004	FTA & EIA
China - Costa Rica	2011	FTA & EIA
China-ASEAN	2005	FTA & EIA
China-Hong Kong	2004	FTA & EIA
China-New Zealand	2008	FTA & EIA
China-Pakistan	2007	FTA & EIA
China-Peru	2010	FTA & EIA
China-Singapore	2009	FTA & EIA
Colombia - Mexico	1995	FTA & EIA
Colombia - Northern Triangle	2009	FTA & EIA
Costa Rica - Peru	2013	FTA & EIA
Costa Rica - Singapore	2013	FTA & EIA

EAEC	1997	CU
EC (9) Enlargement	1973	CU
EC (10) Enlargement	1981	CU
EC (12) Enlargement	1986	CU
EC (15) Enlargement	1995	CU & EIA
EC (25) Enlargement	2004	CU & EIA
EC (27) Enlargement	2007	CU & EIA
EC Treaty	1958	CU & EIA
EC-Algeria	2005	FTA
EC-Bosnia Herzegovina	2008	FTA
EC-CARIFORUM	2008	FTA & EIA
EC-Chile	2003	FTA & EIA
EC-Egypt	2004	FTA
EC-Iceland	1973	FTA
EC-Israel	2000	FTA
EC-Jordan	2002	FTA
EC-Lebanon	2003	FTA
EC-Mexico	2000	FTA & EIA
EC-Morocco	2000	FTA
EC-Norway	1973	FTA
EC-South Africa	2000	FTA
EC-Switzerland Liechtenst0	1973	FTA
EC-Tunisia	1998	FTA
EC-Turkey	1996	CU
EEA	1994	EIA
EFTA - Accession of Iceland	1970	FTA
EFTA - Bosnia and Herzegovina	2015	FTA
EFTA - Central America (Costa Rica and Panama)	2014	FTA & EIA
EFTA - Chile	2004	FTA & EIA
EFTA - Colombia	2011	FTA & EIA
EFTA - Egypt	2007	FTA
EFTA - Hong Kong, China	2012	FTA & EIA
EFTA - Jordan	2002	FTA
EFTA - Lebanon	2007	FTA
EFTA - Mexico	2001	FTA & EIA
EFTA - Morocco	1999	FTA
EFTA - Peru	2011	FTA
EFTA - SACU	2008	FTA
EFTA - Singapore	2003	FTA & EIA
EFTA - Tunisia	2005	FTA
EFTA - Ukraine	2012	FTA & EIA
EFTA-Israel	1993	FTA
EFTA-Korea	2006	FTA & EIA
EU - Andorra	1991	CU
EU - Central America	2013	FTA & EIA
EU - Colombia and Peru	2013	FTA & EIA
EU - Georgia	2014	FTA & EIA
EU - Korea, Republic of	2011	FTA & EIA
EU - Republic of Moldova	2014	FTA & EIA
Egypt - Turkey	2007	FTA

Eurasian Economic Union (EAEU)	2015	CU & EIA
Eurasian Economic Union (EAEU) - Accession of Armenia	2015	CU & EIA
European Free Trade Association (EFTA)	1960	FTA & EIA
GCC	2003	CU
Georgia - Armenia	1998	FTA
Georgia - Kazakhstan	1999	FTA
Georgia - Russian Federation	1994	FTA
Georgia - Ukraine	1996	FTA
Gulf Cooperation Council (GCC) - Singapore	2013	FTA & EIA
Hong Kong, China - Chile	2014	FTA & EIA
Hong Kong, China - New Zealand	2011	FTA & EIA
Iceland - China	2014	FTA & EIA
India-Japan	2011	FTA & EIA
India-Malaysia	2011	FTA & EIA
India-Singapore	2005	FTA & EIA
India-Sri Lanka	2001	FTA
Israel - Mexico	2000	FTA
Japan - Australia	2015	FTA & EIA
Japan - Peru	2012	FTA & EIA
Japan-ASEAN	2008	FTA
Japan-Indonesia	2008	FTA & EIA
Japan-Malaysia	2006	FTA & EIA
Japan-Mexico	2005	FTA & EIA
Japan-Philippines	2008	FTA & EIA
Japan-Singapore	2002	FTA & EIA
Japan-Switzerland	2009	FTA & EIA
Japan-Thailand	2007	FTA & EIA
Jordan - Singapore	2005	FTA & EIA
Korea, Republic of - Australia	2014	FTA & EIA
Korea, Republic of - Turkey	2013	FTA
Korea, Republic of - US	2012	FTA & EIA
Korea, Republic of-India	2010	FTA & EIA
Korea, Republic of-Singapore	2006	FTA & EIA
MERCOSUR	1991	CU & EIA
Malaysia - Australia	2013	FTA & EIA
Mexico - Central America	2012	FTA & EIA
Mexico - Uruguay	2004	FTA & EIA
NAFTA	1994	FTA & EIA
New Zealand - Malaysia	2010	FTA & EIA
New Zealand - Singapore	2001	FTA & EIA
PAFTA	1998	FTA
Pakistan - Malaysia	2008	FTA & EIA
Pakistan - Sri Lanka	2005	FTA
Panama - Chile	2008	FTA & EIA
Panama - Costa Rica (Panama - Central America)	2008	FTA & EIA
Panama - El Salvador (Panama - Central America)	2003	FTA & EIA

Panama - Guatemala (Panama - Central America	2009	FTA & EIA
Panama - Peru	2012	FTA & EIA
Panama - Singapore	2006	FTA & EIA
Peru - Chile	2009	FTA & EIA
Peru - Korea, Republic of	2011	FTA & EIA
Peru - Mexico	2012	FTA & EIA
Peru - Singapore	2009	FTA & EIA
Russian Federation - Belarus	1993	FTA
Russian Federation - Belarus - Kazakhstan	1997	CU
Russian Federation - Kazakhstan	1993	FTA
Russian Federation - Republic of Moldova	1993	FTA
Russian Federation-Ukraina	1994	FTA
SAFTA	2006	FTA
Switzerland - China	2014	FTA & EIA
Thailand - New Zealand	2005	FTA & EIA
Trans-Pacific Strategic Economic Partnership	2006	FTA & EIA
Treaty on a Free Trade Area between members of the Commonwealth of Independent States (CIS)	2012	FTA
Turkey - Bosnia and Herzegovina	2003	FTA
Turkey - Chile	2011	FTA
Turkey - Georgia	2008	FTA
Turkey - Israel	1997	FTA
Turkey - Jordan	2011	FTA
Turkey - Morocco	2006	FTA
Turkey - Tunisia	2005	FTA
Turkey-EFTA	1992	FTA
US - Colombia	2012	FTA & EIA
US - Panama	2012	FTA & EIA
US-Australia	2005	FTA & EIA
US-Chile	2004	FTA & EIA
US-Israel	1985	FTA
US-Jordan	2001	FTA & EIA
US-Morocco	2006	FTA & EIA
US-Peru	2009	FTA & EIA
US-Singapore	2004	FTA & EIA
Ukraine - Moldova	2005	FTA
Ukraine-Belarus	2006	FTA
Ukraine-Kazakhstan	1998	FTA

Source: Hofmann et al. (2017). **Note:** FTA: free trade area. CU: common union. EIA: Economic Integration Agreement.

Table 3 Implementation period and effect of technology-related provisions

Dep variable: DOFI	IPR	RT	IFSO	INPO	DP
Explanatory variables:	(1)	(2)	(3)	(4)	(5)
FTA_zprov	0.999***	0.847***	0.832***	0.831***	0.841***
	(0.0749)	(0.0811)	(0.0784)	(0.0785)	(0.0788)
Ln (distance)	-0.00974	-0.00907	-0.0119	-0.0120	-0.0120
	(0.0139)	(0.0156)	(0.0142)	(0.0142)	(0.0142)
Border	0.615***	0.669***	0.662***	0.661***	0.661***
	(0.0262)	(0.0272)	(0.0264)	(0.0264)	(0.0264)
Language	0.388***	0.371***	0.386***	0.385***	0.383***
	(0.0283)	(0.0279)	(0.0285)	(0.0285)	(0.0284)
Colony	0.0498	0.0306	0.0179	0.0200	0.0213
	(0.0390)	(0.0393)	(0.0397)	(0.0397)	(0.0398)
TRIPS	0.0119	0.0189	0.0239	0.0213	0.0217
	(0.0365)	(0.0378)	(0.0373)	(0.0373)	(0.0374)
FTA_depth	-0.0781***	-0.0564***	-0.0494***	-0.0500***	-0.0532***
	(0.0104)	(0.0108)	(0.0106)	(0.0106)	(0.0106)
DP	-0.355***	-0.132**	-0.0923*	-0.0923*	-0.138
	(0.0556)	(0.0562)	(0.0529)	(0.0529)	(0.0911)
INPO	0.338***	0.261**	0.339**	0.308**	0.309**
	(0.0995)	(0.129)	(0.136)	(0.131)	(0.129)
IFSO	0.164**	-0.0112	-0.162	-0.0162	-0.00755
	(0.0833)	(0.0833)	(0.108)	(0.0854)	(0.0859)
RT	0.276***	0.0780	0.252***	0.262***	0.248***
	(0.0528)	(0.0698)	(0.0556)	(0.0554)	(0.0565)
IPR	0.223***	0.329***	0.311***	0.308***	0.330***
	(0.0623)	(0.0651)	(0.0636)	(0.0636)	(0.0661)
IPR_lag5	0.251***				
	(0.0432)				
IPR_lag10	0.143***				
	(0.0475)				
IPR_lag15	0.172***				
	(0.0500)				
RT_lag5		0.369***			
		(0.0657)			
RT_lag10		-0.0358			
		(0.0651)			
RT_lag15		-0.162***			
		(0.0510)			
IFSO_lag5			0.570***		
			(0.161)		
IFSO_lag10			-0.361**		
			(0.173)		
IFSO_lag15			0.226		
			(0.332)		
INPO_lag5				-0.185	
				(0.341)	
INPO_lag10				2.938***	
				(0.959)	
INPO_lag15				1.546	
				(0.965)	
DP_lag5					-0.0171
					(0.0965)
DP_lag10					0.111
					(0.0783)
DP_lag15					-0.0511
					(0.0779)
Observations	92,251	92,251	92,251	92,251	92,251
R-squared	0.948	0.948	0.947	0.947	0.947

Note: Standard errors in parentheses. Significance level * p<0.1, ** p<0.05, *** p<0.01. Dependent variable *DOFI*. Clustered standard errors clustered at country pair. Estimation using the *ppml_panel_sg* command in Stata (Larch et al., 2019). Park-type Test: null hypothesis states heteroskedastic errors. GNR denotes Gauss-Newton Regression: null hypothesis states CVMR assumption for the functional form of the variance. DP: data protection. INP: Innovation policies. IFSO: Information Society. RT: Research and Technology. IPR: Intellectual Property Rights. Origin-time and destination-time FE were added in all regressions as proxies for multilateral resistance.

Table A.5. Co-inventions as internationalization of technology

Dependent variable: Coinventions	FTA	FTA and FTA-Depth	With Trade Flows	With Trade Flows&Inter
Independent Variables:	(1)	(2)	(3)	(4)
FTA	0.173***	0.281***	0.00888	1.365***
	(0.0166)	(0.0186)	(0.0183)	(0.131)
Ln Imports			0.404***	0.415***
			(0.00830)	(0.00825)
*FTA*ln Imports*				-0.0586***
				(0.00567)
Ln (distance)	-0.113***	-0.0724***	-0.0250***	-0.0246***
	(0.00869)	(0.00933)	(0.00813)	(0.00814)
Border	0.732***	0.765***	0.347***	0.395***
	(0.0189)	(0.0189)	(0.0171)	(0.0187)
Language	0.518***	0.544***	0.518***	0.515***
	(0.0198)	(0.0199)	(0.0174)	(0.0174)
Colony	0.0637***	0.0254	-0.0178	-0.0499**
	(0.0226)	(0.0228)	(0.0206)	(0.0207)
TRIPS	0.0881***	0.196***	-0.000702	0.00505
	(0.0156)	(0.0173)	(0.0181)	(0.0176)
FTA_depth		-0.0757***	-0.0654***	-0.0608***
		(0.00471)	(0.00477)	(0.00469)
Observations	142,902	142,902	109,936	109,936
R-squared	0.964	0.964	0.976	0.