The Effect of Technological Innovation on International Trade

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Abstract   In this paper, the effect of technological innovation on sectoral exports is analysed using a gravity model of trade. The technological achievement index (TAI) and its four components, creation of technology, diffusion of old innovations, diffusion of recent innovations and human skills, are used as proxies for technological innovation. The two first components are considered proxies for knowledge acquisition and assimilation (potential absorptive capacity), whereas the last two are taken as proxies for knowledge transformation and exploitation (realised absorptive capacity). We hypothesise that the effect of technological innovation on trade could vary according to the technological achievement by generating a non-linear relationship between technological innovation and trade. Our findings indicate a positive and non-linear effect of technological innovation on export performance, which indicates that there are thresholds for positive signs to occur. To foster exports, countries have to consider not only acquisition and assimilation capabilities, but also transformation and exploitation capabilities once a minimum level of potential absorptive capacity has been achieved.

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1 Introduction

International trade theory highlights the importance of technological innovation in explaining a country's international competitiveness (Posner 1961; Vernon 1966; Fagerberg 1997). Schumpeter (1944) viewed economic development as a dynamic process deriving from industry and exports, with innovation playing a key role in the development of both.

Empirical work linking trade to technological innovation based on a gravity framework show that the effect of technological innovation on exports varies with country characteristics. Loungani et al. (2002) assessed the importance of information links that associate technological innovation with lower communication costs, and stated that the negative effect of physical distance on trade could be reduced by reducing the barriers to informational flows. These authors distinguished between developed and developing countries when analysing whether better informational infrastructure can substitute for geographical distance. Their results indicate that the degree of substitution between physical and informational distance varies systematically based on country characteristics. The authors tested for a purely linear relationship between informational infrastructure and trade without considering any threshold effects. Fink et al. (2005) analysed the effect of communication costs on bilateral trade flows by taking into account that this effect might vary with sectoral characteristics. Their results show that cross-country variations in communication costs have a significant effect on international trade. Indeed, they found that lower communication costs foster differentiated good trading to a greater extent than homogeneous good trading. Since information and communication needs are much greater for differentiated goods, trade in these products is likely to be more sensitive to variations in communication costs (Harris 1995).

These results may depend on the measure of innovation that is used. Indeed, Kuznets (1962) noted the problems with that the lack of appropriate innovation measures may create in economic research related to inventive activity. In recent years, considerable attempts have been made to measure technological innovation across countries. Wakelin (1997) classified different proxies for technological innovation used in the literature and pointed out that the main choice of technological innovation proxies was between using an input to the innovation process, such as Research and Development (R&D) expenditure or the number of

scientists and engineers employed in research departments, or an output, such as number of patents. In a more recent study, Keller (2004) pointed out that technological innovation is an intangible that is difficult to measure directly and that the three indirect approaches that can be used are the measurement of inputs (R&D), outputs (patents) and the effect of technological innovation (higher productivity).

Technological innovation has been defined as a country's "absorption capacity"—the ability to put information from abroad into practice by developing new products and processes which play a key role in international trade and economic development.[1] Therefore, the development of relevant indicators to measure the level of technological innovation—seen as absorption capacity—across countries is of great interest in a knowledge-based economy with high and increasing dependence on information technology and human capital. Márquez-Ramos et al. (2007) have recently compiled a number of indices and variables to measure the achievement of technological innovation, understood as absorptive capacity. As a nation's technological achievements are very complex, it is difficult to capture them in any single index that reflects the full range of technologies and quantifying aspects of technology creation, diffusion and human skills. This being said, one measure that has attempted to capture technological innovation in a relatively broad manner is the Technological Achievement Index (TAI), which has been used in empirical analyses (Martínez-Zarzoso and Márquez-Ramos 2005; Márquez-Ramos 2007). This index has been constructed using indicators of a country's achievements in four dimensions: creation of technology, diffusion of recent innovations, diffusion of old innovations and human skills. These analyses have shown that technological innovation is of great importance to foster exports.

We can infer from the above-mentioned results that, to the extent that technological innovation is associated with lower communication costs, both internally and externally, we should find similar results as those of Fink et al. (2005) in our empirical application using the TAI index.

The main aim of this paper is to provide empirical evidence on the relationship between technological innovation and international trade. A non-linear relationship between these two variables would indicate that the effect of improved technological innovation on trade could vary according to the technological

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[1] For a review see Zahra and George (2002).

achievement in countries. Hence, the form of heterogeneity we investigate here is whether a country's level of technological innovation achievement (or ability) affects the relationship between technological innovation and trade. This effect is analysed separately, firstly for developed and developing countries to determine whether other differences in economic development also affect the innovation-trade relationship, and secondly for different sectors, in order to pursue the results pioneered by Fink et al. (2005) in a non-linear framework.

The aggregated results show that a "U-shaped" relationship exists between exports and diffusion of old innovations, whereas an inverted U-shaped relationship is found between exports and diffusion of recent innovations and between exports and human skills. With respect to the more specific results, on the one hand the sectoral results indicate that the effect of the importer's TAI on trade is similar for all categories of goods. However, whereas the effect of the exporter's TAI for differentiated goods shows an inverted U-shaped relationship, a U-shaped curve is found for the rest. Hence, while technological innovation improvements seem to have a greater effect on exports of differentiated goods for the intermediate levels of technological achievements, the effect on exports for referenced and homogeneous goods is found to be more marked for the very high levels of technological achievement. On the other hand, the results of the specific country-groups show that when the importer is a developed country, technological achievement has a positive effect on exports which is magnified for higher levels of technological innovation. Otherwise, when the importer is a developing country, a U-shaped relationship between TAI and trade is found.

The importance of our results falls in several areas. Methodologically speaking, we obtain a model of threshold effects of technological innovation on international trade. In terms of policy conclusions, we find that different levels of technological innovation are associated with different effects on exports in developed and developing countries, as well as in different sectors, owing to the existence of threshold effects in the relationship between technological innovation and trade. The main message concerning the development strategy to be followed by developing countries is that, according to our findings, countries exports would benefit from higher levels of technological innovation if they are able to achieve a minimum level of acquisition and transformation capabilities. Hence, investment leading to achieve these thresholds is desirable.

The paper is arranged as follows: Section 2 presents the theoretical framework. Section 3 offers the main hypothesis. Section 4 describes data, sources and variables. Section 5 presents the estimation strategy, the main results and a number of robustness checks. This section also includes an endogeneity analysis as technological variables can be considered endogenous in the gravity model of trade. A final section summarises the main findings.

2   Theoretical Framework

The last few decades have witnessed important changes in international trade patterns, with an increasing number of countries that have become closely linked to one another through international trade and foreign direct investment. Technological innovation plays an important role in this world-wide inter-dependence. Within this framework, international trade theory highlights the importance of technological innovation in explaining the international competitiveness of a country (Fagerberg 1997).

Classical thinking, which stressed international differences in technology in conjunction with international differences in real wage levels as a source of comparative advantage, dominated trade theory until the appearance of the Heckscher–Ohlin (H–O) theory which centred on resource endowments as the main factor explaining international trade patterns.[2] Nevertheless, technological innovation once again came to the forefront of research into trade with the development of the technology gap (Posner 1961) and the product cycle theories (Vernon 1966). On the one hand and according to Posner's assumptions (1961), trade is generated by differences in the rate and nature of innovation. On the other hand, Vernon (1966) places less emphasis on the comparative cost doctrine[3] and more on the timing of innovation. Along these lines, Jones and Bhagwati (1970) considered the way in which the H–O model could be applied to Vernon's product

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[2] Jones (1970) states that "in a sense, the Heckscher-and-Ohlin model represents a step backward from the earlier Ricardian tradition" (page 78).

[3] Comparative advantage is the ability to produce a good at a lower cost, relative to other goods, and compared to another country.

cycle theory. Vernon argued that developed countries tend to have a comparative advantage in producing those commodities, that are newly developed, and suggested a three-factor model: capital, "ordinary" labour, and human skills. Developed countries have a relative abundance of the third factor and, due to the role this factor is assumed to play in the production of new combinations or innovations in particular, developed countries will tend to have a comparative advantage in producing new commodities at early stages of production. Jones (1970) also highlighted the view that technological innovation is improved because there is "learning-by-doing". According to this concept, the higher the level of production (or the more "experience" in the techniques gained by using them), the greater the rate at which these techniques become more productive.

These early papers mainly focused on the timing of innovations and considered R&D investment and human skills as the main drivers of innovation, but do not view the technological innovation process as absorptive capacity. Cohen and Levinthal (1990) introduced the concept of absorptive capacity, which is the ability to recognise the value of new, external information, to assimilate it, and to apply it. These authors consider two faces of technological innovation: creation and absorption. In their model, some level of absorptive capacity is necessary to create, and the cost of adoption increases as absorptive capacity falls. Hence, technological innovation is considered to reduce the cost of adoption. Zahra and George (2002) distinguished not only two subsets (potential and realised absorptive capacity), but also four dimensions of absorptive capacity: acquisition, assimilation, transformation and exploitation capabilities. Knowledge acquisition and assimilation capabilities compose the potential absorptive capacity, whereas knowledge transformation and exploitation compose in the realised absorptive capacity. Their model highlights external sources of knowledge and experience as key antecedents of absorptive capacity. Along these lines, the learning process will lead to an ambiguous effect of technological innovation on exports that will affect the capacity of the country (sector) to acquire, assimilate, transform and exploit new external information. On the one hand, the more "experience" about techniques gained by using them, the greater the rate at which these techniques become more productive. On the other hand, international transmission of new techniques carries a cost because learning-by-doing must occur locally in order to reduce local costs. Hence, the learning process must be taken into account to analyse the relationship between technological innovation and exports at a national

level. This relationship could significantly differ depending on the specific component of technological innovation considered. With respect to the TAI index, a higher potential absorptive capacity could be related to a higher level of technology creation and diffusion of old innovations, whereas a higher realised potential absorptive capacity could be related to a higher level of diffusion of recent innovations and human skills.

Given that different technological innovation components capture the above-mentioned "two faces" (potential and realised) of technological innovation to different degrees, we aim to transfer these concepts into our model, which is specified in the next section. We associate absorptive capacity with the ability to learn and implement the technologies and related practices already used by developed countries (Dahlman and Nelson, 1995). Once countries move from the pre-catching-up and the catching-up stage to the pre-frontier-sharing and the technological frontier, the cumulative nature of the learning process and the increase complexity of external knowledge could result in a non-linear relationship between national absorptive capacity and exports. Once countries achieve a threshold level of absorptive capacity, absorption and catching-up processes may occur rapidly (Criscuolo and Narula, 2008), and firms are able to compete in world markets. Along this line, the expected non-linear relationship between technological innovation and international trade is supported by the findings of Estrada et al. (2006). They found an inverted "U" relationship between some variables related to technological innovation (structural characteristics—size, age and foreign capital intensity—, technological acquisition—machinery and equipment, technological services—and innovative results—new products, product improvements and diversification—) and the probability to export. They also found a "U" effect of R&D intensity on export probability, implying that companies with a very low or very high R&D intensity have a higher export probability than those with a medium R&D intensity.

Eaton and Kortum (2002) developed a Ricardian model to explore the role of trade in spreading the benefits of technological innovation. Their theory delivers an augmented gravity equation for bilateral trade that identifies the underlying parameters affecting the relationship between technological innovation and trade. In a linear specification, their results indicate that foreigners benefit on average by only a tenth as much as the innovating country, but the benefits depend on the

distance to trading partners; the benefits of close neighbours are similar to those of the innovator welfare benefits (measured as real GDP).

We go one step further and ask whether the benefits, in terms of trade, derived from technological innovation depend not only on the origin of the innovation (home or foreign), but also on the level of technological innovation in each country that is linked to the capacity that a given country has to acquire, assimilate, transform and exploit external information. Hence, we investigate the existence of a non-linear relationship[4] whose causality goes from technological innovation to trade, and which accounts for the fact that different stages of the learning process may play a role in determining this relationship.[5] We are aware of the fact that causality could work in the opposite direction,[6] that is, with more trade increasing technology transfer, the so-called technological spillovers, and welfare. While we control for endogeneity in our estimation methodology, we recognise the importance of investigating this reversal effect in detail in future work. The current paper, in line with the work by Eaton and Kortum (2002) and Fink et al. (2005), focuses more narrowly on the technology-foster-trade argument. The importance of studying this specific question relates to the supply-side determinants of exports and competitiveness: the development of new products, which are highly competitive abroad, usually fosters exports, and more trade contributes to improved economic conditions. Hence, this could be used as an argument to determine the innovation and industrial policies to be followed by developing countries to help facilitate their path towards economic development.

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[4] Non-linearity on the relationship between technological innovation and international trade is assessed by means of a quadratic term, quite a common practice in the literature. In most cases, the added squared terms are statistically significant. Hence, a non-linear specification is preferred to a linear one.

[5] Along these lines, Criscuolo and Narula (2008) argued that during the catching-up phase, knowledge accumulation occurs predominately through the absorption of trade and FDI-related R&D spillovers. Then, national absorptive capacity and the accumulation of knowledge stock are simultaneously determined.

[6] To obtain unbiased estimates, we used an instrumental variables estimation procedure that accounts for the endogeneity of the technological variables in the trade model.

3 Main Hypothesis

Pursuing the implications of the work of Cohen and Levinthal (1990) and Zahra and George (2002), our first hypothesis is that the relationship between technological innovation and trade presents a different shape depending on the proxy used to measure technological innovation. We consider four different dimensions of absorptive capacity. In a national-level analysis, we measure acquisition, assimilation, transformation and exploitation capabilities (or dimensions) as creation, diffusion of old innovations, diffusion of new innovations and human skills, respectively.[7] Potential absorptive capacity is a function of the acquisition and assimilation capacities, whereas realised absorptive capacity is a function of transformation and exploitation capabilities. Our results support this first hypothesis since a U-shaped relationship is found between creation of technology and exports and between diffusion of old innovations and exports (potential absorptive capacity), whereas an inverted U-shaped relationship is found between diffusion of recent innovations and exports and between human skills and exports (both of which are proxies for realised absorptive capacity).

Going into the implications of the work of Criscuolo and Narula (2008), our second hypothesis states that developing countries may need a minimum technological innovation level to obtain trade gains derived from higher technological innovation achievements, whereas the already achieved technological innovation level in developed countries is sufficient to obtain trade gains from technological innovation developments. In relation to the related theories, the learning process may affect developed and developing countries differently since absorptive capacity increases diversity of knowledge in trading partners, and this diverse background provides a more robust basis for learning since it increases the prospect of external information relating to what is already known (Cohen and Levinthal 1990). This hypothesis is consistent with the results obtained in this paper, which shows a U-shaped relationship between the importer's creation of technology (national acquisition capability) and trade and between the importer's diffusion of recent innovations (national transformation capability) and trade when the importer is a developing country.

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[7] In a similar fashion as in Zahra and George (2002).

Finally with respect to the type of products traded, our third hypothesis is that the effect of technological innovation on exports should be more robust and greater in magnitude for differentiated products than for homogeneous products. As pointed out by Cohen and Levinthal (1990), absorptive capacity is likely to play a more relevant role for complex products. Fink et al. (2005) and Tang (2006) show that technological innovation is more relevant for trade of sophisticated products, where "sophistication" is measured by product differentiation and high technology content. The results obtained in the present paper show a greater effect of technological innovation in increasing exports of differentiated and high-technology goods for intermediate levels of realised absorptive capacity. This result is consistent with the interpretation that the more experience in techniques gained by producing goods that embody a high technological content, the more the exports.[8]

Our results contribute to the understanding of the literature on technological innovation and trade with two aspects. Firstly, absorptive capacity needs to be built in developing countries before they are able to profit from technological innovation improvements. Secondly, improving absorptive capacity would especially contribute to not only increase exports in sophististicated products, but also eventually to the diversification of exports, which is a widely recognised strategy to foster economic development.

4   Data, Sources and Variables

We obtained bilateral trade data by commodity from Feenstra et al. (2005). The level of disaggregation chosen is 4-digit Standard International Trade Classification (SITC). The initial sample of countries comprised 13 exporters and 167 importers in the year 2000. The 13 exporters were chosen according to the classification matrix constructed in Márquez-Ramos (2007). Due to data limitations concerning the technological innovation variables, the final sample includes 13 exporters and 77 importers in the year 2000.

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[8] Zahra and George (2002) stated that experience will influence the development of a firm's absorptive capacity. These authors pointed out that some experiences are gained from learning-by-doing. This argument can be generalised at a national level.

The databases used to construct the exogenous variables for the regression analysis are Word Bank (2005) for incomes, World Integrated Trade Solution (WITS) for tariffs, and the Doing Business database (2006) for transport costs.[9] Distance between capitals, a common official language and the colonial dummy are taken from CEPII.[10]

Two types of variables are used. First, we specify the income, technological innovation, transport costs, geographical, cultural and integration dummies that vary across countries. Secondly, we specify the tariffs, high-technology and other sectoral dummies that vary across sectors. The high-technology dummy is based on the classification of the Spanish National Statistics Institute (INE).[11] Commodities are defined using the SITC, revision 3, at the 4-digit level. Concordances from the Centre for International data at UC Davis between the SITC revisions 2 and 3 are used since trade data are defined according to the SITC revision 2. Finally, the sectoral dummies are based on Rauch (1999) and were obtained from Jon Haveman's International Trade data web page.

Technological innovation is proxied using the *TAI*, which is a measure introduced by the UNDP in its Human Development Report of 2001. The TAI aims to capture how well a country as a whole is participating in creating, using and diffusing technology and in building a human skill base to acquire knowledge. A nation's technological achievements are very complex and, therefore, it is difficult to capture them in a single index that reflects the full range of technologies and which quantifies all aspects of technology creation, diffusion and human skills. Hence, it is a good measure of technological innovation when viewed as absorptive capacity since it captures both potential absorptive capacity and realised absorptive capacity. In order to create as broad an index as possible,

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[9] This database was recently created by the World Bank and it compiles procedural requirements for exporting and importing a standardised cargo of goods.

[10] The dist_cepii file was taken from:
http://www.cepii.fr/anglaisgraph/bdd/distances.htm.
The language variable is based on the fact that two countries share a common official language (comlang_off). Simple distances are calculated following the great circle formula which uses latitudes and longitudes of the most important cities/agglomerations (in terms of population).

[11] "List of High-Technology products according to the SITC codes and corresponding to codes CNPA-96 and PRODCOM", INE (2006).

however, the TAI was constructed using indicators of a country's achievements in four dimensions: creation of technology, diffusion of old innovations, diffusion of recent innovations and human skills.

As we will be using the disaggregated measures of technological innovation that underline the TAI index in our equations as well as the index as a whole, some additional information on how the index is composed is necessary. At a national level, the creation of a technology index represents part of the potential capacity to innovate. This index is constructed using two indicators to capture the level of technological innovation in a country. The first is the *number of patents granted to residents*, which reflects the current level of invention activities. The second indicator is *receipts of royalty and license fees from abroad*, which indicates the stock of successful innovations made in the past that are still useful. Two additional indicators measure the diffusion of old innovations or the national technological innovation assimilation level, namely *number of telephones (mainline and cellular combined)* and *electricity consumption*. These indicators are important since both are needed to use new technologies and basic related activities. Electricity consumption is also considered a proxy for the use of machinery and equipment since most of it is run by electric power (UNDP, 2001).[12] Both the creation of technology and diffusion of old innovations indices are used here as proxies of potential absorptive capacity.

Two indicators are used to measure the diffusion of recent innovations or the national technological innovation transformation capability. The first, *Internet hosts*, reflects the diffusion of the Internet which enables the fastest transfer of information and an easier adaptation of firms and organisations in a changing environment. The second, *exports of high technology and medium technology products*, illustrates the country's level of specialisation in technologically intensive goods. Finally, the human skills index, or the national exploitation

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[12] Both indicators measuring the diffusion of old innovations are expressed in logarithms with an upper level (average in OECD member countries), allowing to eliminate useless differences among all those countries whose telephony and electricity shares are above the average since they are only relevant at earlier stages of technological advance. Expressing the measure in logarithms ensures that as the level of the index increases, its contribution to the composed index decreases, allowing to discriminate among less developed countries and reflecting the idea that after a certain level, neither telephones nor electricity consumption enriches the technological capacity of a given country.

capability, is measured by two indicators: *mean years of schooling*, representing the fact that people can be users of technology if they have a basic education on which to develop cognitive skills; and the *gross tertiary science enrolment ratio*, showing that the higher the number of inhabitants with the ability to develop skills in science, mathematics and engineering, the greater the number of technology creators. Both diffusion of recent innovations and human skill indices are used as proxies of realised absorptive capacity in the present paper.

The TAI index correlates highly with other national technological innovation indices, such as the ArCo (Archibugi and Coco 2004) and the Information and Communication Technology index (ICT) (Biggs 2003). The ArCo index takes into account three dimensions (creation of technology, diffusion of technology and development of human skills), whereas the ICT index takes into account two dimensions (connectivity and access). Therefore, the TAI index is a more suitable measure of technological innovation since it has more components (four) than competing indices, and this facilitates the distinction between potential and realised absorptive capacity.

Scores are derived as an index in relation to the maximum and minimum scores achieved by countries in any indicator of the four above-mentioned dimensions. The performance of each index takes a value of between 0 and 1, which is calculated according to Equation (1).

$$TAI = \frac{(actual\ value - observed\ \min value)}{(observed\ \max\ value - observed\ \min value)} \qquad (1)$$

The TAI is calculated as a simple average of the four dimension indices, based on the assumption that components play a comparable role of a country's technological achievement. The TAI provides a summary of a society's technological achievements and it allows countries to be classified into four groups according to their level of technological innovation and their stage of knowledge accession (Criscuolo and Narula 2008): Leaders (TAI>0.5) are countries in the technological frontier-sharing stage, Potential Leaders (0.35<TAI<0.49) are countries in the pre-frontier-sharing stage, Dynamic Adopters (0.19<TAI<0.34) are countries in the catching-up stage and Marginalised (TAI<0.19) countries are those in the pre-catching-up stage.

Table A.1[13] in the Appendix shows a summary of the data and sources used in this paper. Table A.2 provides the list of countries classified into all four groups where, for instance, Spain is classified as a potential leader, while Finland has obtained the highest score in the group of technological leaders. The lowest score goes to Mozambique which is classified in the group of technologically marginalised countries.

5 Empirical Analysis

5.1 Model Specification and Estimation Methodology

In order to analyse the effect of technological innovation on sectoral trade, a gravity equation is specified (Bergstrand 1985, 1989; Deardorff 1995) and estimated for the disaggregated data. The estimated equation is:

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\begin{aligned}
\ln X_{ijk} = {} & \alpha_0 + \alpha_1 \cdot \ln Y_i + \alpha_2 \cdot \ln Y_j + \alpha_3 \cdot Adj_{ij} + \alpha_4 \cdot Land_i + \alpha_5 \cdot Land_j + \\
& + \alpha_6 \cdot MERC + \alpha_7 \cdot NAFTA + \alpha_8 \cdot CAN + \alpha_9 \cdot EU + \alpha_{10} \cdot EMU + \\
& + \alpha_{11} \cdot ECOWAS + \alpha_{12} \cdot CEFTA + \alpha_{13} \cdot \ln Dist_{ij} + \alpha_{14} \cdot Lang_{ij} + \\
& + \alpha_{15} \cdot Colony_{ij} + \alpha_{16} \cdot TAI_i + \alpha_{17} \cdot TAI_j + \alpha_{18} \cdot \left(TAI_i\right)^2 + \alpha_{19} \cdot \left(TAI_j\right)^2 + \\
& + \alpha_{20} \cdot \ln Tariffs_{ik} + \alpha_{21} \cdot \ln TC_i + \alpha_{22} \cdot \ln TC_j + \alpha_{23} \cdot high\_tech_k + \alpha_{24} \cdot \hom_k + \\
& + \alpha_{25} \cdot ref_k + \alpha_{26} \cdot DP + \varepsilon_{ijk}
\end{aligned}
\tag{2}
$$

where ln denotes natural logarithms; X_{ijk} denotes the value of exports of commodity k from country i to j; Y_i and Y_j are the incomes in the exporter's market and in the destination market, respectively; Adj_{ij} is a dummy that indicates whether trading partners are contiguous; $Land_i$ and $Land_j$ take the value of 1 when the exporting or importing countries are landlocked, respectively, and zero otherwise.

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[13] The first column lists the variables used for the empirical analysis; the second column outlines a description of the variables, and the third column shows the data sources.

MERC is a dummy that takes a value of 1 when both exporting and importing countries belong to the Mercosur agreement;[14] NAFTA takes a value of 1 when countries are members of the North American Free Trade Area, and CAN is a dummy representing Andean Community members.[15] EU takes a value of 1 when countries are members of the European Union. Additionally, EMU takes a value of 1 when countries are members of the Economic and Monetary Union;[16] ECOWAS takes a value of 1 when countries are members of the Economic Community of West African States.[17] Finally, CEFTA takes a value of 1 when countries are members of the Central European Free Trade Agreement.[18]

$Dist_{ij}$ is the geographical great circle distance in kilometres between the most important cities (in terms of population) of country i and j. $Lang_{ij}$ is a dummy for countries sharing a common official language. $Colony_{ij}$ is a dummy that takes the value of 1 when trading partners have had a colonial link at any time.

$Tariff_{ik}$ is the simple average effectively applied tariff for all the countries importing each commodity from the 13 exporters. TC_i and TC_j are the transport costs of the exporting and importing countries, respectively.

$High\text{-}tech_k$ is a dummy that takes the value of 1 when the commodity is a high-technology commodity. The variable hom_k takes the value of 1 when a commodity is homogeneous, and zero otherwise, whereas ref_k takes the value of 1 when a commodity is reference-priced according to the conservative Rauch classification (1999). The DP dummy is included in the regression to take country-heterogeneity into account. It takes the value of 1 when trading partners are richer than the

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[14] MERCOSUR (Southern Common Market) is a customs union among Argentina, Brazil, Paraguay and Uruguay founded in 1991 by the Treaty of Asunción.

[15] Andean Community of Nations, a South American trade block with Bolivia, Colombia, Ecuador and Peru, signed in 1969.

[16] Greece is also considered because, on 15 January 2000, the Greek government announced the drachma-euro exchange rate with which Greece would enter the third stage of the EU Economic and Monetary Union (EMU) on 1 January 2001.

[17] The Economic Community of West African States (ECOWAS) is a regional group of fifteen West African countries, founded in 1975, with the signing of the Treaty of Lagos.

[18] The parties of the CEFTA agreement are: Albania, Bosnia and Herzegovina, Croatia, Macedonia, Moldova, Montenegro, Serbia and Kosovo. Former parties were Bulgaria, the Czech Republic, Hungary, Poland, Romania, Slovakia and Slovenia, whose CEFTA membership ended when they joined the EU.

sample average. The developed and developing countries considered in the empirical analysis are listed in the Appendix. Finally, ε_{ijk} is the error term, which is assumed to be independently and identically distributed.

As previously indicated, the TAI is used to measure the technological innovation in countries i and j. Then, TAI_i and TAI_j are the technological variables measuring technological innovation in the exporting and importing countries, respectively.[19] To analyse the individual effect of the different dimensions that make up the TAI on international trade, four additional regressions were derived from Equation (2) where we substitute each TAI dimension for the full index.[20] In order to investigate the existence of a non-linear relationship between technological innovation and international trade, two additional terms are included in the model: $(TAI_i)^2$ and $(TAI_j)^2$. Again, to investigate the role of each dimension of the TAI in the innovation-trade relation, this index is decomposed into its four dimensions, and the model is re-estimated with the two additional terms in each dimension. For the regressor diffusion of recent innovations, one of the indicators is exports of high technology and medium technology products. Since all the regressors explain the LHS exports, the collinearity concern is plausible. In order to investigate the presence of multicollinearity, a correlation matrix is built among all the explanatory variables included in the model, and any significant relations are found among them. The simple correlation coefficients are always below 60%. Moreover, the *variance inflation factor* (VIF) is obtained. Tolerance, defined as 1/VIF is used to check the degree of collinearity. A tolerance value lower than 0.1 means that the variable could be considered a linear combination of other independent variables. The tolerance values for the variables used in the estimated gravity model are always higher than 0.1.[21]

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[19] In Márquez-Ramos (2007), a different way to add technological innovation in the trade equation was considered: the variable included was the technological distance between trading partners (Filippini and Molini 2003). A negative correlation between this new variable and the export flows was found.

[20] Including the four components of the TAI and the synthetic index (i.e., the average of the four components) in the same specification would cause important collinearity problems.

[21] A full non-linear specification, based on a polynomial function for not only the TAI but also the other variables, is beyond the scope of this paper, but could be considered a first step in this direction.

Equation (1) is first estimated using Ordinary Least Squares (OLS), the Pseudo Poisson Maximum Likelihood (PPML) method and the Harvey methodology. The Harvey model and the PPML estimator are used as alternative options to control for heteroscedasticity. The PPML method is employed following the observations by Santos-Silva and Tenreyro (2006) in that the standard empirical methods are not appropriate to estimate gravity equations. Log-linearisation leads to inconsistent estimates when observations with heteroscedasticity are present. In addition, the zero values in the dependent variable cannot be considered in the OLS estimation. Moreover, Santos-Silva and Tenreyro (2006) stated that the OLS estimation of the gravity model exaggerates the role of geographical proximity and links. Their results suggest that heteroscedasticity is responsible for the main differences. To address these estimation problems, these authors proposed using the PPML method.

The Harvey model controls for multiplicative heteroscedasticity (Harvey 1976), whereas the PPML method is robust to some kinds of model misspecification, such as heteroscedastic errors. Harvey (1976) proposed a general formulation of a regression model with multiplicative heteroscedasticity, which is more attractive than the usual "additive" model in which the variance of the disturbances is assumed to be related to a linear combination of the known variables.

Causality in this paper is assumed to run from technological innovation to exports; however, higher exports could also foster technological innovation. Poldahl and Gustavsson-Tingvall (2005) analysed whether an inverted "U" relationship exists between competition and technological innovation. These authors used the Herfindahl Index as a measure of the degree of competition in the market. Their results show that breaking up monopolies leads to an increase of R&D expenditure in Swedish companies, whereas further increases in competition leads to lower R&D investment. Although the existence of endogeneity in technological innovation has been analysed using aggregated trade data (Martínez-Zarzoso and Márquez-Ramos, 2005), further research is required to analyse the existence of endogeneity and inverse causality between technological innovation and sectoral trade. Thus, Equation (2) is also estimated using instrumental variables (IV) in order to check the exogeneity assumption concerning technological innovation. If this is true, the IV estimates should be similar to the OLS estimates. To estimate by IV, the use of a set of instrumental variables that

are correlated with technological innovation in countries, but not with the error term of Equation (2), would be desirable. Average research and development expenditure (% of the GDP) in the period 1994–1998 has been selected as an instrument based on Eaton and Kortum (2002). These authors suggested that a country's level of technology is related to its stock of past research effort.

5.2   Technological Innovation and International Trade

Table 1 shows the main results obtained for the technological innovation variables considered.[22] The first part of Table 1 presents the results for the overall TAI index, while the rest of the table shows the results for the disaggregated index dimensions. We restrict attention initially to columns (1)–(4), which show the results obtained when using different estimation methods, namely the OLS, PPML, Harvey and IV models. The above-mentioned endogeneity of technological innovation in the gravity equation is confirmed by the results of a Hausman test[23] that indicates rejection of the null hypothesis of exogeneity. We find a significant difference between the OLS and the IV coefficients, indicating that OLS is an inconsistent estimator of the estimated model, whereas the IV estimator is consistent. The inverted U-Theil criterion is used to compare models with different scales in the dependent variable (the PPML uses exports instead of the logarithm of exports as the dependent variable). Higher values of the inverted U-Theil indicate that one particular model is preferred. According to this criterion, the IV model estimations show a similar performance to the OLS and Harvey methods, and a better performance than the Poisson estimations in terms of forecasting accuracy.[24] Based on these two tests, the IV method is preferred to the rest.

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[22] The results of the other explanatory variables are available upon request from the authors.

[23] The purpose of this test is to indicate whether there is correlation between technological innovation and the error term in the augmented gravity model. The null hypothesis is that there is no correlation and, therefore, that the OLS provides consistent and efficient estimates.

[24] This result has to be interpreted with caution because when the errors are heteroscedastic, and the forecasted value of the log-dependent variables has to be calculated by also using second-order conditions. Only when the appropriate

The IV results obtained for the importer's TAI show that the effect of technological innovation on exports is magnified for higher achievements of technological innovation in the importing country. This indicates a non-linear relationship between trade and technological innovation.[25]

Regarding the exporter's TAI, and according to the results of the preferred instrumental variables, exports increase with technological innovation (measured with the overall index) at a constant rate, and the relationship is linear in this case.[26] Therefore, for those countries classified as Potential Leaders or Technological Leaders, the effect of technological innovation (the TAI index) on exports is always positive and increases with technological improvements for technological innovation in the importing country.

The main difference between our results and those of Estrada et al. (2006)[27] is that these authors focused on the decision to export to a given market (their dependent variable is the probability to export), whereas we centre on the decision of how much to export to a given market (the value exported that is related to the creation and sustenance of competitive advantages).[28] Hence, our results deal with a different aspect of exports and complement rather than compete with these authors' results.

Regarding the magnitude of the estimates of the fourth column of Table 1 (IV), an increase of 10 percentage points in the exporter's TAI index, the equivalent to a change from the level of Brazil (0.306) to the level of Portugal (0.418), is associated with an increase in exports of 8.3 percent. In this case the relationship is

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retransformation of the log-dependent variables is done can the inverted U-Theil obtained for PPML be compared with that obtained with the other methods.

[25] When the OLS, PPML and Harvey methods are in use, the index falls into the increasing part of a "U-shaped" relationship between technological innovation and export elasticity.

[26] Export elasticity also increases with technological innovation when the exporter's TAI values are higher than 0.33 in the OLS regressions, 0.42 in the PPML regressions, and 0.35 in the Harvey regressions.

[27] Estrada et al. (2006) also do a non-linear specification.

[28] According to Zahra and George (2002), a firm's potential absorptive capacity allows it to sustain its competitive advantage, whereas a firm's realised absorptive capacity allows its creation. Similarly, potential and realised absorptive capacities may influence the creation and sustenance of the competitive advantage at a national level.

Table 1. The Effect of Technological Innovation on International Trade

	OLS (1)	PPML[a] (2)	Harvey (3)	IV (4)	IV_65 countries (5)	IV_13 countries aggregated (6)
Exporter's TAI	−1.69***	−8.29***	−2.03***	0.83***	*13.38****	*10.95****
	(−4.84)	(−4.23)	(−6.12)	(15.23)	*(9.03)*	*(3.10)*
Exporter's TAI (square)	2.56***	9.75***	2.90***	–	*−7.43****	*−9.38****
	(7.27)	(4.81)	(8.67)		*(−4.86)*	*(−2.71)*
Importer's TAI	0.07	1.74***	−0.09	0.54***	*10.26****	*1.51***
	(1.21)	(9.44)	(−1.64)	(6.92)	*(7.52)*	*(2.37)*
Importer's TAI (square)	1.05***	–	1.27***	0.31***	*−7.33****	–
	(11.43)		(14.82)	(2.91)	*(−5.10)*	
Exporter's creation of technology	−0.22**	−2.63***	0.05	−0.21*	*9.24****	*2.69***
	(−2.15)	(−5.75)	(0.54)	(−1.94)	*(13.88)*	*(2.26)*
Exporter's creation of technology (square)	1.40***	6.27***	0.92***	1.41***	*−11.43****	*−3.32**
	(8.61)	(7.77)	(5.91)	(8.46)	*(−8.55)*	*(−1.80)*
Importer's creation of technology	−0.81***	−0.77	−0.77***	−0.86***	*5.72****	*3.31****
	(−6.91)	(−1.61)	(−6.85)	(−7.29)	*(7.76)*	*(3.06)*
Importer's creation of technology (square)	2.51***	2.63***	2.45***	2.54***	*−8.06****	*−4.04***
	(10.54)	(3.33)	(10.68)	(10.63)	*(−5.36)*	*(−2.00)*
Exporter's diffusion of old innovations	−6.06***	−19.17***	−4.53***	−6.82***	*−7.73****	*1.81****
	(−9.18)	(−10.65)	(−7.41)	(−5.02)	*(−3.39)*	*(3.38)*
Exporter's diffusion of old innovations (square)	4.13***	11.66***	3.19***	4.52***	*9.18****	–
	(10.35)	(10.49)	(8.63)	(5.55)	*(6.28)*	
Importer's diffusion of old innovations	−1.36***	−0.36	−1.18***	−0.89***	*−2.36*	*−1.26**
	(−23.40)	(−0.66)	(−21.61)	(−9.04)	*(−1.36)*	*(−1.84)*
Importer's diffusion of old innovations (square)	1.47***	0.94**	1.33***	0.97***	*3.94****	*2.43****
	(25.26)	(2.15)	(24.54)	(11.52)	*(3.45)*	*(3.61)*
Exporter's diffusion of recent innovations	0.65***	3.25***	0.51***	0.95***	*7.29****	*1***
	(4.95)	(3.60)	(10.62)	(6.42)	*(11.46)*	*(1.99)*
Exporter's diffusion of recent innovations (square)	−0.26**	−3.68***	–	−0.69***	*−4.09***	–
	(−2.05)	(−3.67)		(−4.83)	*(−5.27)*	
Importer's diffusion of recent innovations	1.00***	2.25***	0.85***	1.03***	*3.81****	*1.38****
	(12.93)	(4.86)	(11.83)	(11.18)	*(6.06)*	*(4.02)*
Importer's diffusion of recent innovations (square)	−0.37***	−1.04*	−0.21**	−0.57***	*−2.09****	–
	(−3.54)	(−1.68)	(−2.16)	(−4.86)	*(−2.61)*	

Table 1 continued

	OLS (1)	PPML[a] (2)	Harvey (3)	IV (4)	IV_65 countries (5)	IV_13 countries aggregated (6)
Exporter's human skills	0.89***	4.37***	0.11***	1.91***	*11.19***	*6.49***
	(5.36)	(3.36)	(3.81)	(10.06)	*(10.94)*	*(3.50)*
Exporter's human skills (square)	–0.73***	–4.82***	–	–1.65***	*–6.21***	*–5.17***
	(–4.96)	(–3.75)		(–9.75)	*(–6.98)*	*(–3.21)*
Importer's human skills	–0.06	2.46***	–0.16**	0.17	*6.89***	*3.54***
	(–0.91)	(4.98)	(–2.45)	(1.35)	*(7.05)*	*(3.25)*
Importer's human skills (square)	0.47***	–1.71***	0.57***	0.19*	*–4.22***	*–1.96*
	(6.21)	(–3.58)	(7.95)	(1.67)	*(–4.76)*	*(–1.93)*
1-U Theil	0.82	0.56	0.82	0.82	*0.85*	*0.91*
R-squared	0.25	0.35	0.24[29]	0.24	*0.76*	*0.86*
Number of observations	149,985	149,992	149,985	123,250	*1,895*	*799*

Notes: [a]When the Poisson model is $E[Y_i|x_i] = \exp[\beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3]$, it is possible to interpret β_1 as a semi-elasticity: $\partial \log E[Y_i|x_i]/\partial x_{i1} = \beta_1$.

***, **, * indicate significance at 1%, 5% and 10%, respectively, *t*-statistics are in parentheses. The dependent variable is the natural logarithm of exports in value (current US$). The OLS and IV estimation uses White's heteroscedasticity-consistent standard errors. In those cases where the term of innovation technology squared is found to be non-significant, a linear relationship is estimated.

Source: Own calculations based on the constructed database (see Section 4).

linear according to the IV results, whereas in the case of the importer's TAI index, the effect of technological innovation on exports increases with higher achievements of technological innovation in the importing country. For example, if we consider the average value of the TAI for importers (0.36), an increase in 10 percentage points in the importer's TAI index increases exports by 7.63 (10x[0.54+2x0.36x0.31]) percent.

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[29] This is the VWLS (variance-weighted least squares) R2, which is obtained by using the inverse of the estimated variances in the heteroscedastic model as weights in the corresponding regression model.

*Figure 1*. The TAI Effect on Exports. IV Estimation
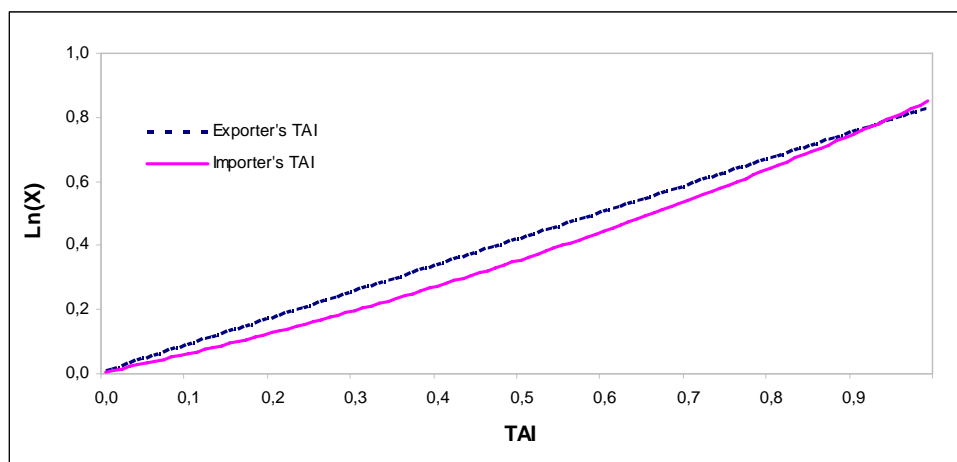
Source: Own calculations based on the constructed database (see Section 4).

Figure 1 shows the effect of technological innovation on export elasticities for different values of the TAI index when estimating by the IV method.

Concerning the different TAI dimensions, we firstly refer to the results obtained for the two TAI dimensions related to the above-mentioned concept of potential absorptive capacity that can be decomposed into acquisition and assimilation capabilities. The results show that the creation of technology dimension, a proxy for the acquisition capacity, ranges in the growing part of the "U" (see Figure 2). The minimum value of this variable in the exporting country is equal to 0.074 according to the IV estimates. With this value, the model mainly predicts that the greater the creation of technology, the more the exports. For the second dimension, diffusion of old innovations, related to the assimilation capability, the results show a U-shaped relationship between the elasticity of exports and this dimension.[30] This relationship becomes considerably more

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[30] The components of the index diffusion of old innovations are expressed in logarithms to ensure that as the level of the index increases, its contribution to the composed index decreases. Although a "U-shaped" relationship between technological innovation and exports is found when applying any of the four estimation methodologies considered, the

*Figure 2*. The Creation of Technology Effect on Exports. IV Estimation
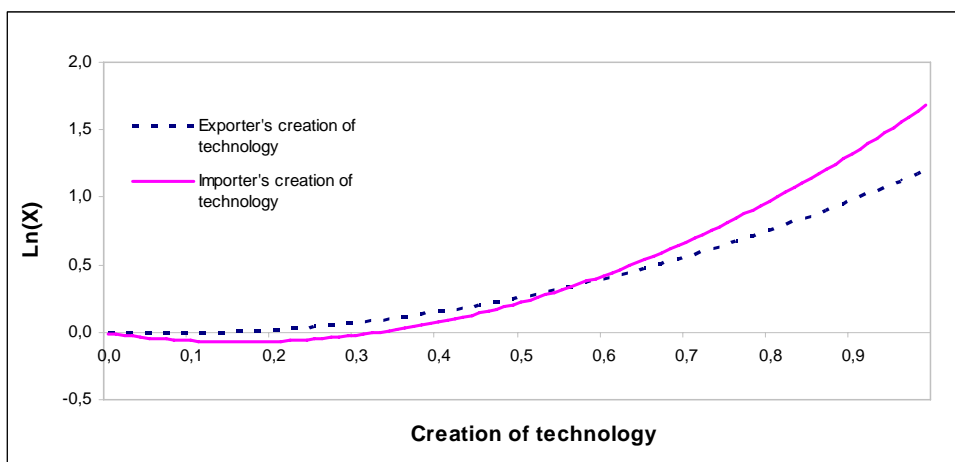
Source: Own calculations based on the constructed database (see Section 4).

pronounced in the exporter's case. The minimum value of the diffusion of old innovations variable in the exporting country is 0.75 when estimating by IV.[31] This result indicates that there is a minimum threshold up to which exports increase with higher levels of diffusion of old innovations. In relation to the realised absorptive capacity measures, the results obtained for the diffusion of recent innovations, a proxy for the transformation capability, show that there is an inverted U-shaped relationship between this variable and exports according to the IV estimates. The maximum of this TAI component in the exporter's case is found to be 0.68 (Figure 3). Exporters with an intermediate achievement of diffusion of recent innovations show a higher increase in exports than those countries with a low or a very high level. Otherwise the results for importers reveal that the diffusion of recent innovations dimension mainly ranges in the growing part of the inverted "U". Then, a more developed transformation capability, which is a component of realised absorptive capacity, increases exports to a higher extent.

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results are not shown graphically since an important part of the index falls in the negative values of lnX.

[31] Similar values are obtained with the other methods: 0.73, 0.82 and 0.71 when estimating by the OLS, PPML and Harvey methods, respectively.

Figure 3. The Diffusion of Recent Innovations Effect on Exports. IV Estimation
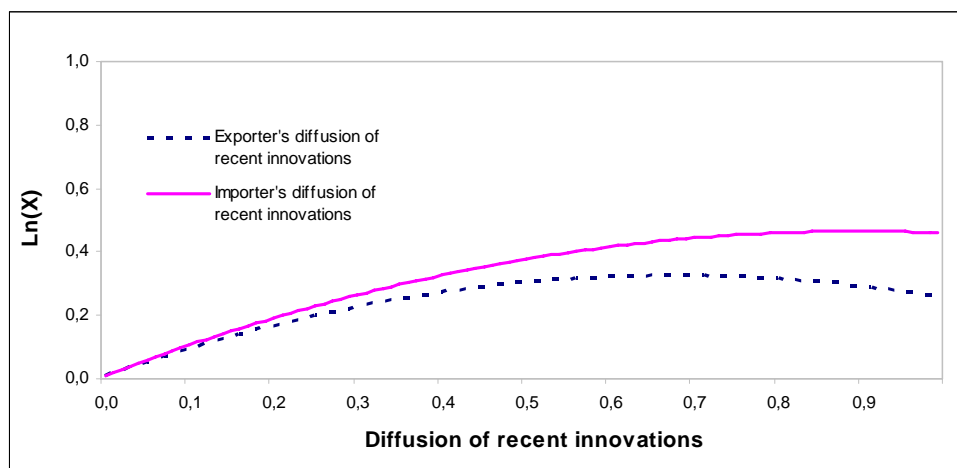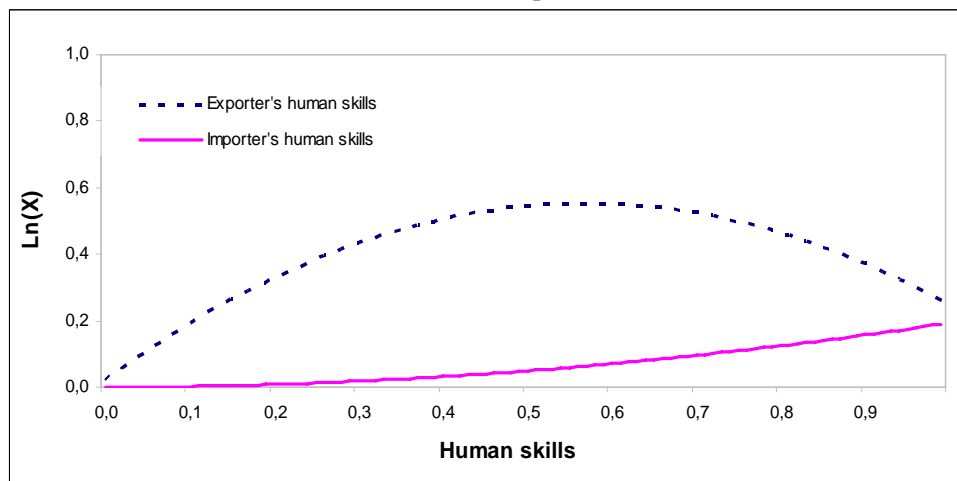

Source: Own calculations based on the constructed database (see Section 4).

Finally as regards to the human skills dimension, a proxy for the exploitation capacity, which is the second component of realised absorptive capacity, the IV results show that the coefficient of the human skills dimension in the importing country ranges in the growing part of a "U" relationship between this dimension and exports (Figure 4). These results indicate that the higher the trading partners' human skills (realised absorptive capacity), the higher the positive effect of this variable on trade. With respect to the exporter's human skills, an inverted U-shaped relationship is found when using IV (the maximum equals 0.58).[32]

The second hypothesis states that developing countries may need a minimum technological level to obtain trade gains derived from higher technological innovation achievements. To test this hypothesis, Equation (2) is estimated for developed and developing importing countries separately. The obtained results, according to the IV estimation (first part of Table 2), show that when the importer

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[32] For this dimension, different results were obtained according to the estimation technique used. An inverted "U-shaped" relationship was also observed when using OLS (the maximum equals 0.6) and PPML (the maximum equals 0.45); the relationship between this variable and trade was linear when estimating by the Harvey method.

Figure 4. The Human Skills Effect on Exports. IV Estimation

Source: Own calculations based on the constructed database (see Section 4).

is a developed country, technological innovation has a positive effect on exports which is magnified for the higher levels of the TAI. As found in the analysis performed for the full country-sample, a U-shaped relationship is found between relationship is found between realised absorptive capacity and exports. Otherwise, when the importer is a developing country, a U-shaped relationship is found potential absorptive capacity and exports, whereas an inverted U-shaped between importer's creation of technology and exports and between importer's diffusion of recent innovations and exports. The minimum value of developing importer's creation of technology and diffusion of recent innovations is equal to 0.09 and 0.07, respectively. With this value, the model mainly predicts that the greater the acquisition and transformation capabilities in developing importing countries, the higher the increase on trade. Furthermore, an inverted U-shaped relationship is found between importer's diffusion of old innovations and exports and between importer's human skills and exports. The maximum value of developing importer's diffusion of old innovations and human skills are 0.79 and 0.35, respectively. Up to this value, the model mainly predicts that the greater the assimilation and exploitation capabilities in developing importing countries, the higher the increase on trade. These results show that the development of both

Table 2. The Effect of Technological Innovation on International Trade. Country and Sector Heterogeneity

IV estimation	Technological innovation	Technological innovation squared
By Type of Importer:		
Importer is a developed country		
Exporter's TAI	2.3***	–0.92*
	(3.71)	(–1.71)
Importer's TAI	–0.02	0.33**
	(–0.16)	(2.17)
R-squared	0.23	
Number of observations	90,639	
Importer is a developing country		
Exporter's TAI	–3.74***	4.41***
	(–4.7)	(5.54)
Importer's TAI	0.32	1.42**
	(1.38)	(2.24)
R-squared	0.17	
Number of observations	32,611	
By Type of Product:		
Differentiated[a]		
Exporter's TAI	8.99***	–8.22***
	(16.34)	(–14.80)
Importer's TAI	0.61***	0.28**
	(6.64)	(2.21)
R-squared	0.26	
Number of observations	84,619	
Referenced		
Exporter's TAI	–5.17***	6.19***
	(–6.33)	(7.57)
Importer's TAI	0.71***	–
	(9.82)	
R-squared	0.23	
Number of observations	31,894	

Table 2 continued

IV estimation	Technological innovation	Technological innovation squared
Homogeneous		
Exporter's TAI	–14.59***	14.77***
	(–7.04)	(7.08)
Importer's TAI	0.38	0.86*
	(0.94)	(1.67)
R-squared	0.12	
Number of observations	6,737	

Notes**:** ***, **, * indicate significance at 1%, 5% and 10%, respectively; *t*-statistics are in parentheses. The dependent variable is the natural logarithm of exports in value (current US$). The IV estimation uses White's heteroscedasticity-consistent standard errors**.** In those cases where the term of innovation technology squared is found to be non-significant, a linear relationship is estimated. [a]Similar conclusions are drawn for high-technology goods, although the coefficients obtained are higher than those obtained for differentiated goods.

Source: Own calculations based on the constructed database (see Section 4).

potential and realised absorptive capacities in technologically marginalised developing countries would increase their participation in international trade.[33]

Next, we test the third hypothesis which states that the effects of technological innovation on exports should be greater in magnitude for differentiated products than for homogeneous products. Equation (2) is estimated for exports of differentiated, referenced and homogeneous goods. Table 2 shows the obtained results for the overall index for IV, which shows in most cases a non-linear relationship between technological innovation and trade.

We can compare the results in Table 2 with column (4) in Table 1. Whereas the results of the effect of the importer's TAI on trade are similar for all categories of goods, the effect of the exporter's TAI differs for differentiated products and for the rest. For differentiated goods, the exporter's TAI shows an inverted U-shaped relationship, whereas a U-shaped curve is found for reference-priced goods and homogeneous goods. While technological improvements have a higher effect on exports of differentiated goods for the intermediate levels of technological

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[33] The results of the different TAI dimensions are available upon request from the authors.

achievements, the effect on exports for referenced and homogeneous goods shows the opposite pattern as it is found to be higher for very high levels of technological achievement. With respect to the different components of the TAI index, exporter's acquisition capability presents a U-shaped relationship, whose minimum value is 0.08. Therefore, the model mainly predicts that the greater the acquisition capability, the higher the increase on trade of differentiated goods. Concerning exporter's transformation and exploitation capabilities, both have a greater positive effect on exports of differentiated goods for the intermediate levels of technological achievements, which is consistent with the interpretation that the more experience in techniques gained by producing goods that embody a higher technological content, the more the exports.[34]

5.3   Robustness Checks

As a first robustness check, we performed the same analysis for aggregated trade flows using a larger sample of countries. We used a 65-country sample which uncovers the 65-country sample selected in Márquez-Ramos (2007) by using data for 1999. The last two columns of Table 1 show the obtained results when estimating Equation (2) for both the 65-country and the 13-exporter (aggregated) samples. The results show that the coefficients obtained for technological innovation are higher than those obtained when using disaggregated data. As in the disaggregated analysis, a U-shaped relationship was found between exports and the diffusion of old innovations, whereas an inverted U-shaped relationship was seen between exports and the diffusion of recent innovations, and between exports and human skills. However, we observe reversal of signs for the variables related to creation of technology. In columns (5) and (6) exporter's and importer's creation of technology show an inverted U-shaped relationship with aggregated exports. This fact is most probably due to aggregation bias and indicates the importance of using disaggregated trade data in empirical analysis. Creation of technology is having a different effect for each category of goods and therefore we have to rely on the results obtained in column (4).

As a second robustness check, the model specification was tested with both the disaggregated 13-exporter and the aggregated 65-country sample. A model

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[34] The results of the different TAI dimensions are available upon request from the authors.

specification error may occur when one or more relevant variables is/are omitted from the model, or when one or more irrelevant variables is/are included in the model. Model specification errors can substantially affect the estimated coefficients of regression. The *linktest* command in STATA was used, and the Ramsey test was done to test for specification errors.[35] We find that the Ramsey test results indicate that our estimates may suffer from an omitted variable bias. However, this bias most likely is related to trade cost variables and not the coefficients of the target variable, technological innovation.

6   Conclusions

This paper aims to provide empirical evidence on the relationship between technological innovation and international trade. In order to do so, technological innovation is understood as absorptive capacity that is decomposed into potential and realised absorptive capacities. At a national level, potential absorptive capacity is composed of the acquisition (creation of technology) and assimilation (diffusion of old innovations) capabilities, which provides flexibility to change and allows the sustenance of competitive advantage, whereas realised absorptive capacity is composed of the transformation (diffusion of recent innovations) and exploitation (human skills) capabilities, which allows the creation of competitive advantage. The Technological Achievement Index (TAI) and its four components are used in the empirical analysis since they are considered suitable measures of technological

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[35] The linktest is based on the idea that if a regression is properly specified, then it should not be possible to find any additional independent variables that are significant, other than by chance. The linktest creates two new variables, a variable of the prediction (_hat) and a variable of the square prediction (_hatsq). The model is then refitted using these new variables as predictors. The former should be significant since it is the predicted value, unlike the latter because, if the model is correctly specified, the squared predictions should not have much explanatory power.

In a first step, the linktest is calculated for the disaggregated and aggregated analyses where both the variable of prediction (_hat) and the variable of square prediction (_hatsq) are significant. As a second step, the hypothesis that the model has no omitted variables is rejected with the Ramsey RESET Test.

innovation including acquisition, assimilation, transformation and exploitation capabilities.

Our findings indicate a positive and, in most cases, non-linear effect of technological innovation on export performance. Additionally, the results obtained show the existence of a non-linear relationship between trade and all the technological dimensions considered. Firstly, creation of technology fosters international trade in all countries, independently of its achievement. Secondly, a U-shaped relationship is observed between diffusion of old innovations and exports. Thirdly, and in the case of realised absorptive capacity measures (diffusion of recent innovations and human skills), an inverted U-shaped relationship with exports is observed. Fourthly, the non-linear relationship also holds in developed and developing countries, as well as in different sectors. Our results are consistent with the "learning-by-doing" and the "absorptive capacity" concepts.

A natural extension of this research would be to use a panel dataset to fully account for unobserved country heterogeneity and to study the dynamics of the relationship between trade and technological innovation. The question of how the causality relationship goes from trade to technological innovation in a non-linear framework is still open and requires further research.

Appendix

Table A.1. Variable Descriptions and Sources of Data

Variable	Description	Source
X_{ijk} : Exports from i to j of the commodity k	Value of exports from the 13 selected countries to 167 countries, in thousands of US dollars in the year 2000	Feenstra et al. (2005)
Y_i : Exporter's income	Exporter's GDP, PPP (current international $)	World Bank (2005)
Y_j : Importer's income	Importer's GDP, PPP (current international $)	World Bank (2005)
Adj_{ij} : Adjacency dummy	Dummy variable = 1 if the trading partners share a common border, 0 otherwise.	CEPII (2006)
$Land_i$: Landlocked dummy	Dummy variable = 1 if the exporting country is landlocked, 0 otherwise.	CEPII (2006)
$Land_j$: Landlocked dummy	Dummy variable = 1 if the importing country is landlocked, 0 otherwise.	CEPII (2006)
MERC dummy	Dummy variable = 1 if the trading partners are members of Mercosur, 0 otherwise	
NAFTA dummy	Dummy variable = 1 if the trading partners are members of NAFTA, 0 otherwise	
CAN dummy	Dummy variable = 1 if the trading partners are members of CAN, 0 otherwise	
EU dummy	Dummy variable = 1 if the trading partners are members of the European Union, 0 otherwise	
EMU dummy	Dummy variable = 1 if the trading partners are members of the Economic and Monetary Union, 0 otherwise	
ECOWAS dummy	Dummy variable = 1 if the trading partners are members of ECOWAS, 0 otherwise	
CEFTA dummy	Dummy variable = 1 if the trading partners are members of CEFTA, 0 otherwise	
$Dist_{ij}$: Distance	Great circle distances between the most important cities in trading partners	CEPII (2006)
$Lang_{ij}$: Language dummy	Dummy variable = 1 if the trading partners share the same official language, 0 otherwise.	CEPII (2006)

Table A1 continued

Variable	Description	Source
$Colony_{ij}$: Colony dummy	Dummy variable = 1 if the trading partners have ever had a colonial link, 0 otherwise.	CEPII (2006)
TAI_i : Exporter's TAI	Technological variable	UNDP (2001), author's calculations
TAI_j : Importer's TAI	Technological variable	UNDP (2001), author's calculations
$Tariffs_{ik}$	Effectively applied rates in sector k	WITS (2006) http://wits.worldbank.org/witsnet/StartUp/Wits_Information.aspx
TC_i: Exporter's transport costs	Transport costs (US$ per container)	Doing Business (2006)
TC_j: Importer's transport costs	Transport costs (US$ per container)	Doing Business (2006)
High-tech dummy	Dummy variable = 1 when commodity is a high-technology commodity, 0 otherwise	
Hom_k dummy	Dummy variable = 1 when a commodity k is homogeneous, according to Rauch classification (1999), 0 otherwise	Jon Haveman's International Trade Data web page http://www.macalester.edu/research/economics/PAGE/HAVEMAN/Trade.Resources/TradeData.html
Ref_k dummy	Dummy variable = 1 when a commodity k is reference-priced, according to Rauch classification (1999), 0 otherwise	Jon Haveman's International Trade Data webpage
Average R&D expenditure (% of GDP) during the period 1996–1999	TAI instrument	World Bank (2005)

Table A.2. The Technology Achievement Index

Technological Leaders			Dynamic Technological Adopters		
1	Finland	0.745	43	Uruguay	0.339
2	United States	0.733	44	South Africa	0.335
3	Sweden	0.704	45	Thailand	0.330
4	Japan	0.697	46	Trinidad and Tobago	0.323
5	Rep. of Korea	0.664	47	Panama	0.317
6	Luxembourg	0.634	48	Brazil	0.306
7	Netherlands	0.628	49	China	0.293
8	United Kingdom	0.604	50	Philippines	0.292
9	Singapore	0.595	51	Bolivia	0.270
10	Switzerland	0.595	52	Colombia	0.270
11	Canada	0.589	53	Peru	0.265
12	Australia	0.587	54	Jamaica	0.256
13	Germany	0.581	55	Iran	0.253
14	Norway	0.580	56	Paraguay	0.248
15	Ireland	0.564	57	Tunisia	0.248
16	Belgium	0.551	58	El Salvador	0.248
17	New Zealand	0.548	59	Ecuador	0.247
18	Denmark	0.547	60	Dominican Republic	0.238
19	Austria	0.542	61	Syrian Arab Republic	0.233
20	Iceland	0.540	62	Egypt	0.228
21	France	0.534	63	Algeria	0.212
22	Israel	0.513	64	Zimbabwe	0.210
Potential Technological Leaders			65	Indonesia	0.202
23	Spain	0.479	66	Honduras	0.199
24	Italy	0.470	67	Sri Lanka	0.194
25	Czech Republic	0.462	68	India	0.191
26	Hungary	0.461	Technologically Marginalised		
27	Slovenia	0.456	69	Nicaragua	0.175
28	Hong Kong, China	0.453	70	Pakistan	0.156
29	Slovakia	0.444	71	Senegal	0.148
30	Greece	0.436	72	Ghana	0.127
31	Portugal	0.418	73	Kenya	0.116
32	Bulgaria	0.408	74	Nepal	0.070
33	Poland	0.402	75	Tanzania	0.066
34	Malaysia	0.392	76	Sudan	0.058
35	Croatia	0.388	77	Mozambique	0.053
36	Cyprus	0.384			
37	Mexico	0.383			
38	Argentina	0.376			
39	Rumania	0.365			
40	Turkey	0.355			
41	Costa Rica	0.354			
42	Chile	0.353			

Notes:

Technological Leaders (above 0.5*)*. This group includes countries with a high capability to create and sustain technological innovation.

Potential Technological Leaders (from 0.35 to 0.49). This group includes countries that have invested in all four dimensions, but have been less innovative.

Dynamic Technological Adopters (from 0.19 to 0.34). The countries in this group attempt to accomplish growth in both their technology content and their level of development.

Technologically Marginalised (below 0.19). The last group consists of marginalised countries: many African countries belong to this block. It is difficult for them to gain access even to the oldest technologies and a low technological level is associated with low income levels. The relative position is not particularly meaningful due to the lack of adequate data.

Developed countries: Argentina, Australia, Austria, Belgium, Canada, Chile, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hong Kong, Hungary, Iceland, Ireland, Israel, Italy, Japan, Rep. of Korea, Luxembourg, Malaysia, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Trinidad and Tobago, United Kingd*om, United States.*

Developing countries: Algeria, Bolivia, Brazil, Bulgaria, China, Colombia, Dominican Republic, Ecuador, Egypt, El Salvador, Ghana, Honduras, India, Indonesia, Iran, Jamaica, Kenya, Mozambique, Nepal, Nicaragua, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Senegal, Sudan, Sri Lanka, Syrian Arab Republic, Tanzania, Thailand, Tunisia, Turkey, Uruguay, Zimbabwe.

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