The effect of technological innovation on international trade. A non-linear approach

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Abstract

This paper focuses on the relationship between technological innovation and international trade. In particular, the effect of technological achievement on exports is studied. In order to measure technological innovation, the technological achievement index (TAI) is used, thus providing a summary of a society's technological achievements and allowing countries to be classified into four groups according to their level of technological innovation: Leaders, Potential Leaders, Dynamic Adopters and Marginalised.

The effect of technological variables on sectoral exports is analysed using a gravity model of trade. The existence of a possible non-linear relationship is also investigated, since the effect of improved technological innovation on trade could vary according to the technological achievement in countries. Results show the expected positive effect of technological innovation on export performance and the existence of non-linearities is confirmed. A "U-shaped" relationship is found between exports and creation of technology and 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.

1. Introduction

The international trade theory highlights the importance of technological innovation in explaining a country's international competitiveness (Fagerberg, 1997). According to Schumpeter (1883-1950), economic development is a dynamic process deriving from industry and trade. This author identifies different causes of economic development related to trade such as introducing a new quality of a good, or a new use of an already existing good, a new production method, opening up of a new market, and a change in economic organisation. Then, technological innovation can be defined as the countries' capacity to put new ideas into practice by developing new products and processes which play a key role in international trade and economic development. Therefore, the development of relevant indicators to measure the level of technological innovation across countries is of great interest in a knowledge-based economy with a high and increasing dependence on information technology and human capital. Kuznets (1962) already noted the problems 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 technology creation and diffusion, and human skills across countries. Márquez Ramos, Martínez Zarzoso, Sanjuan Lucas and Suárez Burguet (2007) have recently compiled a number of indices and variables to measure the achievement of technological innovation. Nonetheless, a nation's technological achievements are very complex. Therefore, it is difficult to capture them in an index that reflects the full range of technologies and which quantifies some aspects of technology creation, diffusion and human skills. In order to overcome these inconveniences, the Technological Achievement Index (TAI) has been used in empirical analyses (Martínez Zarzoso and Márquez Ramos, 2005). 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.

Additionally, empirical applications show that heterogeneity matters in technological innovation. Loungani, Mody and Razin (2002) distinguish between developed and developing countries when analysing whether better information can substitute geographical distance. Their results indicate the existence of country-heterogeneity in the different determinants of international trade since they show that technological innovation is a "substitute" for distance in developing countries (better information lowers the effect of distance), whereas technological innovation and distance are "complementary" in developed countries (better information magnifies the effect of distance). This may occur when trade in differentiated products dominates, and when physical proximity and high information technology reinforce each other in fostering trade. Developing countries can overcome the disadvantage of distance by investing in technological innovation. Fink, Mattoo and Neagu (2005) analyse the effect of communication costs on bilateral trade flows by taking into account sector-heterogeneity. Their results show that communication costs have a significant effect on international trade and that they are of greater importance for trading differentiated products than for trading homogeneous products. Then, technological innovation is seen to have a greater effect on the trade of differentiated goods since information asymmetries exist and, therefore, a lower demand of this type of goods in foreign markets exists.

The main aim of this paper is to analyse the effect of technological innovation on trade by taking into account sector and country heterogeneity. Moreover, the existence of a possible non-linear relationship is investigated, since the effect of improved technological innovation on trade could vary according to the technological achievement in countries.

The obtained results show that a non-linear relationship exists between exports and the creation of technology and between exports and diffusion of old innovations, which is in both cases "U-shaped", whereas an inverted-"U-shaped" relationship is found between exports and diffusion of recent innovations and between exports and human skills.

The paper is arranged as follows: Section 2 presents the calculation of a comparative advantage index. Section 3 describes how a classification matrix is constructed from this index, and 13 exporting countries are selected for the empirical analysis. 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 presents an endogeneity analysis. Technological variables can be considered endogenous in the gravity model of trade since higher trade among countries deals with higher technological innovation. A final section summarises the main findings.

2. Revealed comparative advantage

A revealed comparative advantage (RCA) index is used to select a representative country sample that represents different specialisation patterns. The RCA index is calculated according to Balassa's measure of relative export performance by country and industry (1965) to determine in which goods are specialised the countries being considered in the analysis. The index is defined as a country's share of world exports of a given good divided by its share of total world exports, as expressed in Equation (1):

$$\boldsymbol{RCA_{ik}} = \frac{\boldsymbol{X_{ik}} / \boldsymbol{X_{wk}}}{\boldsymbol{X_{iN}} / \boldsymbol{X_{wN}}} \cdot 100 \qquad (1)$$

where RCA_{ik} is the RCA index of commodity k for country i, X_{ik} is the value of commodity k exported by country i, X_{wk} is the value of world exports of commodity k, X_{iN} is the value of the exports of all the commodities by country i, and X_{wN} is the value of world exports of all the commodities. A ranking of the first ten industries with the highest positive RCA values is drawn up for each country in the year 2000.[1] According to Equation (1), country i has a comparative advantage in exporting commodity k when RCA_{ik} is greater than one.[2]

The Rauch classification is used to determine whether countries are specialised in goods traded on an organised exchange (homogeneous), reference-priced or differentiated goods (Rauch, 1999). Specialisation patterns are as follows: developing Asian countries (China, India, Nepal and Pakistan) mainly specialise in differentiated products, whereas developing African countries (Egypt, Mozambique and Sudan) specialise in homogeneous goods. A number of high-income countries mainly specialise in differentiated and reference-priced products, whereas others, Canada, France, Ireland, Hong Kong, Japan, Singapore, Switzerland-Liechtenstein, United Kingdom, and the United States, tend to specialise in high-technology sectors.

Finally, a number of medium-income countries, mainly Mediterranean, Central-Eastern European and Latin American countries, specialise in differentiated and reference-priced goods.

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[1] Suárez, Fernández and García (1996) point out that this index indicates an "exporting advantage" more than a comparative advantage since imports are not taken into account.

[2] A table including those sectors in which all the 65 countries of the sample (see Figure A.1, Appendix) are specialised has been contructed. See Márquez Ramos (2007), pp. 142-156.

3. Classification matrix

A classification matrix is constructed to choose a representative sample for the sectoral analysis. Classifications by country (developed and developing countries) and by commodity (Rauch, 1999: differentiated, reference-priced and homogeneous) are considered. The information in Márquez Ramos (2007) is used to determine whether countries specialise in differentiated, reference-priced or homogeneous goods. For example, when a country is more specialised[3] in differentiated goods (ranked in the 10 most exported goods) than in reference-priced or homogenous goods, then, it is considered to be specialised in differentiated goods.[4] A representative country is chosen from each group (in boldface in Table 1). When a high number of countries is classified in the same group, two representative countries are chosen for the empirical analysis as follows: Bolivia, Brazil and Chile for Latin America; the United States for North America; China and Japan for Asia; the Czech Republic, Germany, Spain and the United Kingdom for Europe; Ghana and South Africa for Africa; Australia for Oceania.

[3] Specialisation can be defined as "producing more than you need of some things, and less of others, hence specialising in the first". Definition obtained from Deardorff's Glossary of International Economics (http://www-personal.umich.edu/~alandear/glossary/).

[4] When a country has the same number of differentiated, reference-priced and homogeneous commodities in the ranking, it is included in more than one group (e.g., Finland).

Table 1. Classification matrix.

	Differentiated	**Reference-priced**	**Homogeneous**
High-income	Austria Belgium, Luxembourg Finland France, Monaco **Germany** Hong Kong Ireland Italy **Japan** Sweden Switzerland, Liechtenstein	**Australia** Belgium, Luxembourg Canada Denmark Finland Iceland Ireland Netherlands Norway **United Kingdom** United States	France, Monaco Singapore **United States**
Medium-income	Bulgaria Colombia Costa Rica **Czech Republic** Dominican Republic Greece Mexico Panama Paraguay Portugal El Salvador Slovak Republic South Korea **Spain** Turkey	**Chile** Costa Rica Croatia Cyprus Israel Peru Poland **South Africa** Spain Syrian Arab Republic Trinidad and Tobago Turkey Venezuela	Algeria Argentina **Brazil** Bulgaria Uruguay
Low-income	**China** Honduras India Jamaica Kenya Nepal Nicaragua Pakistan Tanzania	Ecuador **Ghana** Nicaragua Senegal	**Bolivia** Egypt Mozambique Nicaragua Sudan

Note: Countries are classified into three groups as follows: countries are ordered from higher to lower income levels (GDP per capita, PPP in 1999. Source: WDI, 2005), then an upper level and inferior level of GDP are calculating by the average of the first half and the average of the second half of the sample, respectively. Commodities are classified according to Rauch (1999).

4. Data, sources and variables

Bilateral trade data by commodity derive from Feenstra, Lipsey, Deng, Ma and Mo (2005). The level of disaggregation chosen is 4-digit SITC. The sample of countries considered includes 13 exporters and 77 importers in the year 2000. The final sample includes 146 sectors with homogeneous goods, 349 sectors with reference-priced goods, and 694 sectors with differentiated goods.

The databases used to construct the exogenous variables for the regression analysis are World Development Indicators (2005) for incomes, World Integrated Trade Solution (WITS) for tariffs, and Doing Business (2006) database for transport costs. This database was recently created by the World Bank and it compiles procedural requirements for exporting and importing a standardised cargo of goods. Distance between capitals, common official language and the colonial dummy were taken from CEPII.[5]

Two types of variables are used: income, technological innovation, transport costs, geographical, cultural and integration dummies vary across countries, whereas tariffs, high-technology and sectoral dummies vary across sectors. 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 an index that reflects the full range of technologies and which quantifies some aspects of technology creation, diffusion and human skills. In order to overcome these inconveniences, the TAI was 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. The creation of a technology index represents the capacity to innovate. Two indicators are

[5] 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).

used to capture the level of 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. The diffusion of recent innovations index and the diffusion of old innovations index represent the importance that adopting new technologies and participation in the information and knowledge age has for countries. Since technological advance is a cumulative process, diffusion of older innovations is necessary in order to adopt later innovations. Two indicators are used to measure the diffusion of recent innovations. 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*, which illustrates the country's level of specialisation in technologically intensive goods. Two additional indicators measure the diffusion of old innovations, namely number of telephones 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. Finally, the human skills index 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.

Scores are derived as an index in relation to the maximum and minimum achieved by countries in any indicator of these dimensions. The performance of each index takes a value of between 0 and 1 which is calculated according to Equation (2).

$$\boldsymbol{I}1 = \frac{(\boldsymbol{actual\ value} - \boldsymbol{observed}\ \min \boldsymbol{value})}{(\boldsymbol{observed} \max\ \boldsymbol{value} - \boldsymbol{observed} \min \boldsymbol{value})} \tag{2}$$

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: Leaders (TAI>0.5), Potential Leaders (0.35<TAI<0.49), Dynamic Adopters (0.19<TAI<0.34) and Marginalised (TAI<0.19). Table A.1 shows the list of countries classified in all four groups where, for instance, Spain is classified as a potential leader, whereas Finland has the highest score in the group of technological leaders. The lowest score goes to Mozambique which is classified within the group of technologically marginalised countries.

The high-technology dummy is based on the classification of the Spanish National Statistics Institute (INE).[6] Commodities are defined using the Standard International Trade Classification (SITC), revision 3 at the 4-digit level. Concordances from the Centre for International data at UC Davis between SITC revisions 2 and 3 are used since trade data are defined according to SITC revision 2. Finally, the sectoral dummies are based on

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

Rauch (1999) and were obtained from Jon Haveman's International Trade data web page. Table A.2[7] shows a summary of the data and sources used in this paper.

5. Empirical analysis

5.1. Determinants of sectoral trade

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:

$$\begin{aligned}
\ln X_{ijk} &= \alpha_0 + \alpha_1 \cdot \ln Y_i + \alpha_2 \cdot \ln Y_j + \alpha_3 \cdot Adj_{ij} + \alpha_4 \cdot Land_i + \alpha_5 \cdot Land_j + \\
&+ \alpha_6 \cdot MERC + \alpha_7 \cdot NAFTA + \alpha_8 \cdot CAN + \alpha_9 \cdot EU + \alpha_{10} \cdot EMU + \\
&+ \alpha_{11} \cdot ECOWAS + \alpha_{12} \cdot CEFTA + \alpha_{13} \cdot \ln Dist_{ij} + \alpha_{14} \cdot Lang_{ij} + \\
&+ \alpha_{15} \cdot Colony_{ij} + \alpha_{16} \cdot TAI_i + \alpha_{17} \cdot TAI_j + \alpha_{18} \cdot (TAI_i)^2 + \alpha_{19} \cdot (TAI_j)^2 + \\
&+ \alpha_{20} \cdot \ln Tariffs_{ik} + \alpha_{21} \cdot \ln TC_i + \alpha_{22} \cdot \ln TC_j + \alpha_{23} \cdot high_tech_k + \alpha_{24} \cdot \hom_k + \\
&+ \alpha_{25} \cdot ref_k + \alpha_{26} \cdot DP + \varepsilon_{ijk}
\end{aligned} \tag{3}$$

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 the 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.

MERC is a dummy that takes a value of 1 when both exporting and importing countries belong to Mercosur; 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. 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

[7] Table A.2 in the Appendix. 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.

Monetary Union;[8] ECOWAS takes a value of 1 when countries are members of the Economic Community of West African States. Finally, CEFTA takes a value of 1 when countries are members of the Central European Free Trade Agreement.

$Dist_{ij}$ 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.

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. To analyse the individual effect of the different dimensions composing the TAI on international trade, four additional regressions were derived from Equation (3) where TAI can be substituted by its four dimensions. In order to analyse 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 $(TAI_j)^2$. Then, this index is decomposed into its four dimensions and the model is again estimated with the two additional terms in each dimension.

$Tariff_{ik}$ 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.

[8] 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.

High-tech$_k$ is a dummy that takes the value of 1 when the commodity is a high-technology commodity. *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 sample average. Finally, ε_{ijk} is the error term, which is assumed to be independently and identically distributed.

Equation (3) is estimated using Ordinary Least Squares (OLS), Pseudo Poisson Maximum Likelihood (PPML) methods and Harvey methodologies. The Harvey model and the PPML estimator are used as alternative options to control heteroscedasticity. The PPML method is employed following the observations by Santos-Silva and Tenreyro (2006), these being 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) state 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 propose using the PPML method.

The Harvey model controls multiplicative heteroscedasticity, whereas the PPML method is robust to some kinds of model misspecification, such as heteroscedastic errors. Harvey (1976) proposes 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 derive from technological innovation to exports; however, higher exports could also foster technological innovation. Poldahl and Gustavsson-Tingvall (2005) analyse whether an inverted-"U" relationship exists between competition and technological innovation. These authors use 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 the endogeneity and inverse causality between technological innovation and sectoral trade. Thus, Equation (3) is also estimated using instrumental variables (IV).

Table 2 shows the main results obtained for the technological variables considered. Results concerning the other explanatory variables[9] in the model indicate that geographical variables, distance, adjacency and landlocking are significant and that they present the expected sign. Sharing a common language increases exports. With regard to regional integration, being a member of Mercosur, NAFTA, the Andean Community, the European Economic and Monetary Union and CEFTA has a positive effect on exports. The positive and significant high-tech dummy shows that technologically intensive sectors are highly exported. Similar results were obtained in the Harvey estimations. Otherwise, a number of differences are obtained when estimating Equation (3) by PPML. The distance variable presents a lower negative coefficient than when using OLS and the

[9] These results are available upon request from the authors.

language variable is not significant. In contrast to Rauch (1999), OLS and PPML estimates show that countries sharing colonial ties trade less. Higher magnitudes are found in the coefficients of technological innovation and trade costs variables. Finally, country-heterogeneity is more pronounced since the DP dummy is higher in magnitude, thus indicating that developed countries trade more among themselves. The results obtained can be compared to other studies that use disaggregated trade data, such as that of Siliverstovs and Schumacher (2006). These authors also show that geographical distance coefficients are significantly lower in magnitude in PPML estimates than in OLS estimates.

5.2. Technological innovation and international trade

The first part of Table 2 presents the obtained results for the overall index, while the rest of the table shows the results of its different dimensions. Columns 2, 3, 4 and 5 show the results obtained when using different estimation methods, namely the OLS, PPML, Harvey and the IV. When using the OLS, PPML and Harvey methods, the results obtained for the importer's TAI show that the index falls into the increasing part of a "U-shaped" relationship between technological innovation and exports. This indicates a possible linear relationship between trade and technological innovation. However, when applying the IV estimator the effect of technological innovation on exports is magnified for higher achievements of technological innovation in the importing country.

In terms of the exporter's TAI, for TAI values higher than 0.33 in the OLS regressions, 0.42 in the PPML regressions, and 0.35 in the Harvey regressions; exports always increase with technological innovation. Therefore, for those countries classified as potential leaders, the effect of technological innovation on exports is always positive and increases with technological improvements.

Similarly, Estrada, Heijs and Buesa (2006) have also shown the existence of a non-linear relationship between technological innovation and international trade. According to these authors, a non-linear relationship exists between these variables since companies require a minimum level of technological innovation to compete in world markets. At this level, the export probability would increase to innovation effort until a particular level where the export probability would be constant. Their results show that a non-linear relationship exists, particularly an inverted-"U" effect for a number of cases, and that a "U" effect between technological innovation and export probability is also possible. For instance, these authors note that those companies with a low and high R&D intensity have a higher export probability than those with a medium R&D intensity; however, other variables related to technological innovation (structural characteristics, technological adquisition and innovative results) show that an inverted-"U-shaped" relationship is also possible between the innovation level and the export probability.

Table 2. The effect of technological innovation on international trade.

	OLS	PPML[10]	Harvey	IV	*IV_65 countries*	*IV_13 countries aggregated*
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)	
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[11]	0.24	0.76	0.86

[10]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: $\partial \log E[Y_i|x_i] / \partial x_{i1} = \beta_1$

Number of observations	149,985	149,992	149,985	123,250	*1,895*	*799*

Notes: ***, **, * indicate significance at 1%, 5% and 10%, respectively. T-statistics are in brackets. The dependent variable is the natural logarithm of exports in value (current US$). The 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.

Concerning the different TAI dimensions, the results show that the creation of technology dimension only ranges in the growing part of the "U". The minimum value of this variable in the exporting country is equal to 0.078; 0.074 and 0.2 in OLS, IV and PPML, respectively. With these values, the model predicts that the greater the creation of technology, the more exports. For the second dimension, diffusion of old innovations, the results show a "U-shaped" relationship between the elasticity of exports and this dimension when applying any of the four estimation methodologies considered. This relationship becomes considerably more pronounced in the exporter's case. The minimum value of the diffusion of old innovations variable in the exporting country is 0.73; 0.82; 0.71 and 0.75 when estimating by OLS, PPML, Harvey and IV, respectively. This result indicates that those countries with a lower and a higher endowment of diffusion of old innovations export more.

The results obtained for the diffusion of recent innovations show that there is an inverted-"U-shaped" relationship between this variable and trade according to three of the four methodologies used (the Harvey regression shows a linear relationship). The maximum of this TAI component in the exporter's case is found to range between 0.44 (PPML) and 0.68 (IV). Countries with an intermediate achievement of diffusion of recent innovations export more than countries with a lower or higher level.

[11] 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.

Finally, the OLS, Harvey and IV regressions show that the human skills dimension in the importing country ranges in the growing part of a "U" relationship between this dimension and exports. When the PPML estimation is used however, the simulations show that this dimension in the importer's case mostly comprises the growing part of an inverted-"U-shaped" curve, where the maximum found is 0.72. This result indicates that the higher trading partners' human skills are, the lower the positive effect of this variable on trade is. With exporter's human skills, different results were also obtained according to the estimation technique used. Firstly, an inverted-"U-shaped" relationship was observed when using OLS (the maximum equals to 0.6), PPML (the maximum equals to 0.45) and IV (the maximum equals to 0.58), and the relationship between this variable and trade was linear when estimating by Harvey.

Figures A.2-A.6 in the Appendix show a simulation of the effect of technological innovation on export elasticities in the 13-exporter sample according to the TAI (and its components) when estimating by the IV method.

5.3. Robustness

A number of robustness checks are presented in this section. Firstly, the inverted U-Theil criterion is used to compare models with different scales in the dependent variable. Higher values of the inverted U-Theil indicate that one particular model is preferred. According to this criterion, the Harvey model estimations show a better performance than the Poisson estimations in terms of forecasting accuracy.[12]

[12] This result has to be taken with caution because when the errors are heteroscedastic the forecasted value of log-dependent variables has to be calculated using also second order conditions. Only when the appropriate retransformation of log-dependent variables is made, the inverted U-Theil obtained for PPML can be compared with the one obtained with the other methods.

Secondly, Equation (3) is estimated by OLS, PPML, Harvey and IV for exports of differentiated, referenced and homogeneous goods, respectively. Table 3 shows the obtained results for the overall index, which show in most cases a non-linear relationship between technological innovation and trade.

Table 3. The effect of technological innovation on international trade. Sector-heterogeneity.

	Technological innovation (TAI)			
	OLS	PPML	Harvey	IV
Differentiated				
Exporter's TAI/Exporter's TAI (squared)	4.45***/-3.66***	1.12***	1.98***/-1.17***	8.99***/-8.22***
Importer's TAI/Importer's TAI (squared)	0.13*/1.08***	1.88***	0.02/1.17***	0.61***/0.28**
R-squared	0.28	0.38	0.26	0.26
Number of observations	103,852	103,856	103,852	84,619
Referenced				
Exporter's TAI/Exporter's TAI (squared)	-4.59***/ 5.59***	-8.92***/10.93***	-5.39***/6.33***	-5.17***/6.19***
Importer's TAI/Importer's TAI (squared)	-0.03/0.99***	1.19***	-0.25**/1.34***	0.71***
R-squared	0.23	0.34	0.23	0.23
Number of observations	38,273	38,275	38,273	31,894
Homogeneous				
Exporter's TAI/Exporter's TAI (squared)	-5.33***/5.28***	1.93***	-8.27***/ 8.27***	-14.59***/14.77***
Importer's TAI/Importer's TAI (squared)	-0.35/1.42***	1.61***	-0.59***/1.48***	0.38/0.86*
R-squared	0.11	0.22	0.65	0.12
Number of observations	7,860	7,861	7,860	6,737

Notes: ***, **, * indicate significance at 1%, 5% and 10%, respectively. The dependent variable is the natural logarithm of exports in value (current US$). The 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.

If we take the IV results as the preferred ones, we can compare column 5 in Table 3 with column 5 in Table 2. Whereas the results concerning the effect of the importer's TAI on trade are similar for all categories of goods, the effect of the exporter's TAI is considerably different for differentiated products and the rest. For differentiated goods, the exporter's TAI shows an inverted "U-shaped" relationship, whereas for referenced-price goods and homogeneous goods, a "U-shaped" curve is found. Whereas technological improvements have a higher effect on exports of differentiated goods for intermediate levels of technological achivements, the effect on exports for referenced and homogeneous goods shows an opposite pattern, and it is found to be higher for very high levels of technological achievement. Finally, Equation (3) is also estimated for the 13-exporting country sample for both developed and developing importing countries. The obtained results show that when the importer is a developed country, technological achievement has a positive effect on exports that is magnified for higher levels of TAI. Otherwise, when the importer is a developing country, a "U-shaped" relationship between technological innovation and trade is found. The minimum for the exporter's TAI is found to be 0.45, whereas it is found to be 0.09 for the importer's TAI, thus meaning that technological improvements and the development of human skills in technologically marginalised developing countries would increase their participation in international trade.[13]

Thirdly, as an additional robustness check, we perform the same analysis for aggregated trade flows using a larger sample of countries. We use a 65-country sample which uncovers the countries selected in Figure A.1 (Appendix) by using data for 1999. The last two columns of Table 2 show the obtained results when estimating Equation (3) for both the 65-country and the 13-exporter (aggregated) samples. 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. Otherwise, the opposite results were found for the dimension of creation of technology since an inverted "U-shaped" relationship was noted between exports and creation of technology with the aggregate samples.

[13] These results are available upon request from the authors.

Although gravity models are, in most cases, estimated using OLS, this specification does not account for the existence of causality between technological innovation and trade. Since this is a potential problem that will lead to a misspecification of the estimated model, the possible endogeneity of technological innovation in the gravity equation is analysed in this paper. In this case, technological innovation will be correlated with the error term, while the OLS estimates will be biased and inconsistent.

In order to test the presence of endogeneity, a Hausman test is performed in the 65-country sample. 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 OLS provides consistent and efficient estimates. 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 (3), would be desirable. Average research and development expenditure (% of GDP) and average public spending on education (% of GDP) in the period 1994–1998 were selected as technological innovation instruments. The selection of the instrumental variables is based on Eaton and Kortum (2002). These authors suggest that a country's level of technology is related to its stock of past research effort, and that a higher stock of human capital allows a country to absorb more ideas from abroad.

The version of the Hausman test proposed by Davidson and MacKinnon (1993) is also applied to validate the results. In a first step, technological innovation (TAIi) is regressed on all the exogenous variables and on an instrument to obtain the residuals. Then in a second step, the augmented gravity model is estimated including the residuals from the first regressions as an additional variable. When R&D expenditure is used as a proxy for technological innovation, the residuals of those regressions are not significant in the augmented gravity model. Since the coefficients on the first-stage residuals do not significantly differ from zero for R&D expenditure, the test indicates that there is no endogeneity problem. Therefore, the OLS estimation is consistent. However, when public spending on education is included as a technological innovation instrument, the residuals of those regressions are significant in the augmented gravity model. Thus when public spending on education is included as an instrument, the test accepts the hypothesis of endogeneity.

Finally, whether the instrumental variables chosen are valid is also investigated. The first requirement of good instruments is that they must be highly correlated with the variable for which they are instrumenting. Table 4 shows that the research and development expenditure and the public spending on education are highly significant in explaining technological innovation.

Table 4. First Stage Regression.

Variable		
Constant term	*0.28**** *(118.01)*	*0.21**** *(17.55)*
Research and development expenditure	*0.14**** *(85.26)*	-
Public spending on education	-	*0.04**** *(14.52)*
R-squared	*0.761*	*0.122*
Number of observations	*2867*	*3782*

*Notes: ***, **, *, indicate significance at 1%, 5% and 10%, respectively. T-statistics are shown in brackets. The dependent variable is the exporter's technological innovation. The estimation uses White's heteroscedasticity-consistent standard errors.*

The second requirement of good instruments is that they must be uncorrelated with the error term of the export equation. To determine this, the residual of the OLS regression is regressed in the instruments. The results show that the instruments used independently are indeed correlated with the error term. In fact this indicates that the instruments chosen are not the best. However, Cyrus (2002) points out that this test is a very difficult test to pass, and that it may be better to examine the R-squared of these regressions. The results show that the variables used as instruments for income and technology have a low explanatory power (all the instruments have a R-squared value below 0.0063) in the error term regressions.

Finally, the model specification is also checked with both the disaggregated 13-exporter and the aggregated 65-country sample. A model specification error may occur when one or more relevant variables are omitted from the model, or when one or more irrelevant variables are included in the model. Model specification errors can substantially affect the estimated coefficients of regression. The linktest command in STATA is used, and the Ramsey test has been done to test for specification errors.

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 except 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 analysis where both the variable of prediction (_hat) and the variable of square prediction (_hatsq) are significant. In a second step, the hypothesis that the model has no omitted variables is rejected with the Ramsey RESET Test. This indicates that further research is needed to improve the specification of the estimated model.

6. Conclusions

This paper aims to provide empirical evidence on the relationship between technological innovation and international trade. The results obtained in the analysis show a positive relationship between technological innovation and exports. For those countries classified as technological leaders and potential leaders, the effect of technological innovation on exports is always positive, and this effect is magnified by technological improvements.

Moreover, there is a non-linear relationship in a number of technological dimensions. Firstly, creation of technology fosters international trade in all countries, independently of its achievement. Secondly, in the case of diffusion of old innovations, a “U-shaped” relationship between this TAI component and exports is observed. Countries with an intermediate diffusion of old innovations export the less. Thirdly, in the case of diffusion of recent innovations and human skills, an inverted-“U-shaped” relationship with exports is observed. Therefore, a low and a high level of these components lead to lower exports, whereas an intermediate achievement leads to higher exports.

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APPENDIX

Figure A.1. Selected countries.

Algeria
Argentina
Australia
Austria
Belgium-Luxembourg
Bolivia
Brazil
Bulgaria
Canada
Chile
China
Colombia
Costa Rica
Croatia
Cyprus
Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt, Arab Rep.
El Salvador
Finland
France
Germany
Ghana
Greece
Honduras
Hong Kong, China
Iceland
India
Ireland
Israel
Italy
Jamaica
Japan
Kenya
Korea, Rep.
Mexico
Mozambique
Nepal
Netherlands
Nicaragua
Norway
Pakistan
Panama
Paraguay
Peru
Poland
Portugal
Senegal
Singapore
Slovak Republic
South Africa
Spain
Sudan
Sweden
Switzerland
Syrian Arab Republic
Tanzania
Trinidad and Tobago
Turkey
United Kingdom
United States
Uruguay
Venezuela

Figure A.2. The TAI effect on trade elasticity. IV estimation.

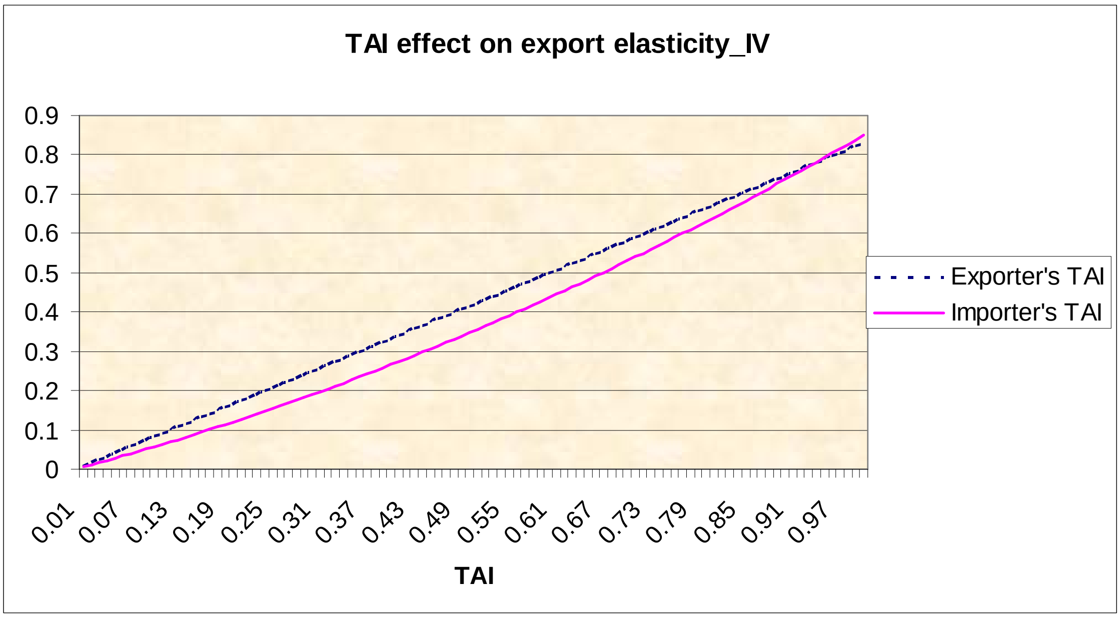

Figure A.3. The creation of technology effect on trade elasticity. IV estimation.

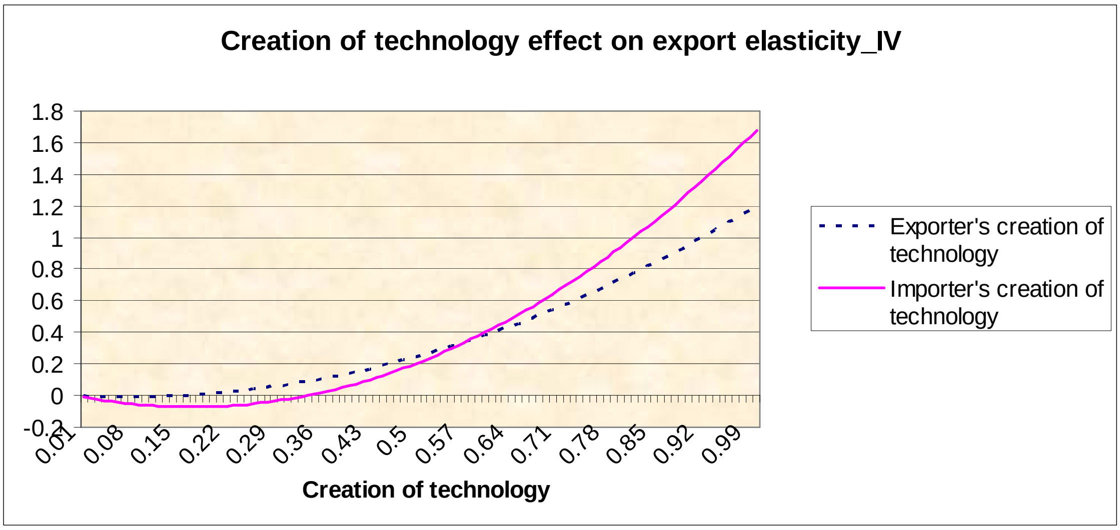

Figure A.4. The diffusion of old innovations effect on trade elasticity. IV estimation.

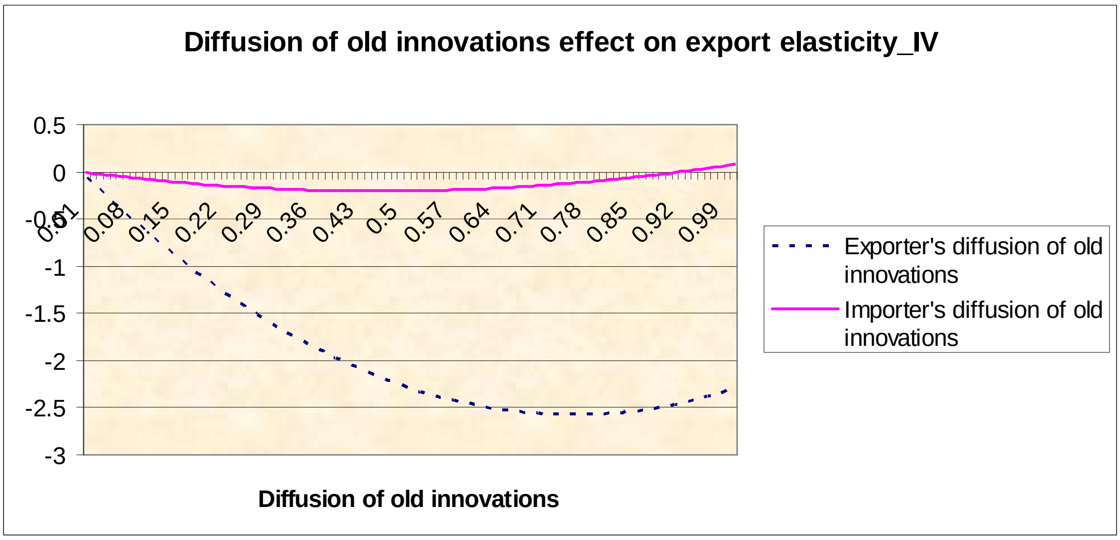

Figure A.5. The diffusion of recent innovations effect on trade elasticity. IV estimation.

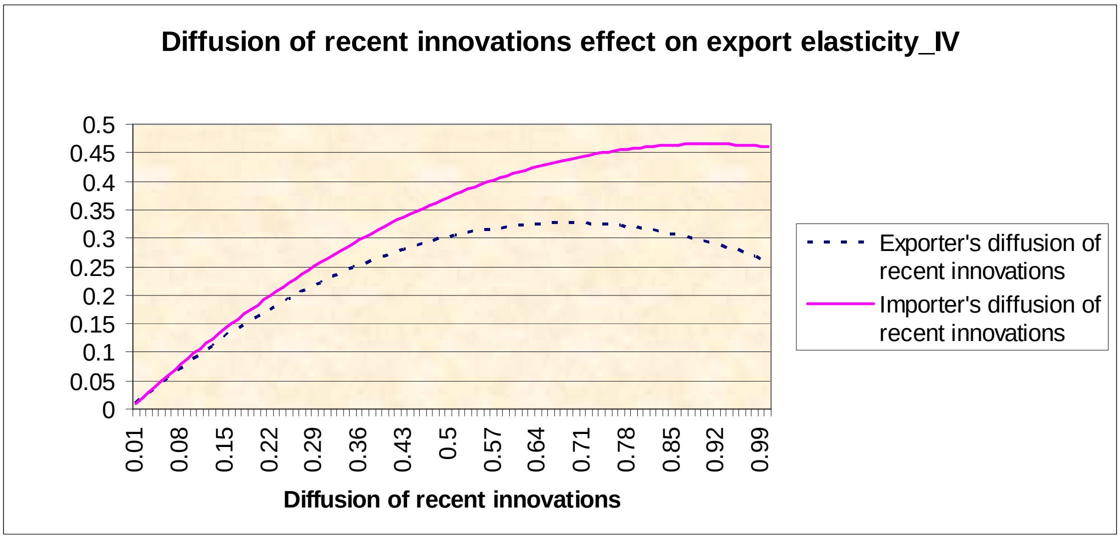

Figure A.6. The human skills effect on trade elasticity. IV estimation.

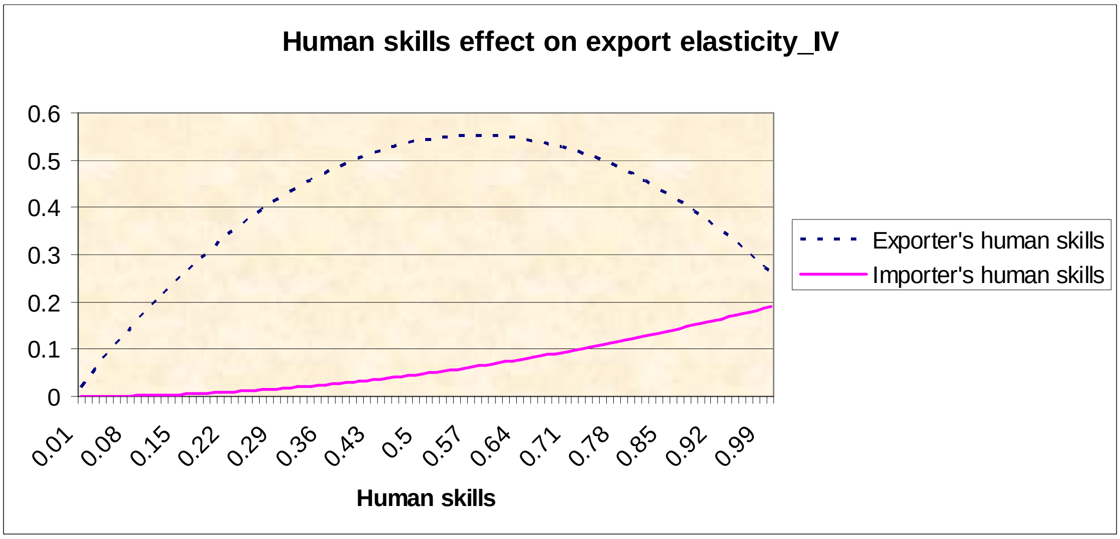

Table A.1. The Technology Achievement Index.

Technological Leaders		
1	Finland	0.745
2	United States	0.733
3	Sweden	0.704
4	Japan	0.697
5	Rep. of Korea	0.664
6	Luxembourg	0.634
7	Netherlands	0.628
8	United Kingdom	0.604
9	Singapore	0.595
10	Switzerland	0.595
11	Canada	0.589
12	Australia	0.587
13	Germany	0.581
14	Norway	0.580
15	Ireland	0.564
16	Belgium	0.551
17	New Zealand	0.548
18	Denmark	0.547
19	Austria	0.542
20	Iceland	0.540
21	France	0.534
22	Israel	0.513
Potential Technological Leaders		
23	Spain	0.479
24	Italy	0.470
25	Czech Republic	0.462
26	Hungary	0.461
27	Slovenia	0.456
28	Hong Kong, China	0.453
29	Slovakia	0.444
30	Greece	0.436
31	Portugal	0.418
32	Bulgaria	0.408
33	Poland	0.402
34	Malaysia	0.392
35	Croatia	0.388
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

Dynamic Technological Adopters		
43	Uruguay	0.339
44	South Africa	0.335
45	Thailand	0.330
46	Trinidad and Tobago	0.323
47	Panama	0.317
48	Brazil	0.306
49	China	0.293
50	Philippines	0.292
51	Bolivia	0.270
52	Colombia	0.270
53	Peru	0.265
54	Jamaica	0.256
55	Iran	0.253
56	Paraguay	0.248
57	Tunisia	0.248
58	El Salvador	0.248
59	Ecuador	0.247
60	Dominican Republic	0.238
61	Syrian Arab Republic	0.233
62	Egypt	0.228
63	Algeria	0.212
64	Zimbabwe	0.210
65	Indonesia	0.202
66	Honduras	0.199
67	Sri Lanka	0.194
68	India	0.191
Technologically Marginalised		
69	Nicaragua	0.175
70	Pakistan	0.156
71	Senegal	0.148
72	Ghana	0.127
73	Kenya	0.116
74	Nepal	0.070
75	Tanzania	0.066
76	Sudan	0.058
77	Mozambique	0.053

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). 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.

Table A.2. 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) http://www.cepii.fr/anglaisgraph/bdd/distances.htm
$Lang_{ij}$: Language dummy	Dummy variable = 1 if the trading partners share the same official language, 0 otherwise.	CEPII (2006)
$Colony_{ij}$: 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)