INTERNATIONAL TRADE, TECHNOLOGICAL INNOVATION AND INCOME: A GRAVITY MODEL APPROACH

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ABSTRACT

In this research, we estimate a gravity equation augmented with technological innovation and transport infrastructure variables in order to analyse the impact of these variables on international trade. According to our results, investing in transport infrastructure and technological innovation leads to the improvement and maintenance of the level of competitiveness. Moreover, our results support the hypothesis that countries tend to trade more when they are "closer" from a technological point of view and that the development of information technology has lowered the effect of geography on trade.

Keywords: gravity model, technology, infrastructure, international trade

RESUMEN

En este trabajo, estimamos un modelo de gravedad ampliado con variables de innovación tecnológica y de infraestructura de transporte con el fin de analizar el impacto de estas variables sobre el comercio internacional. Según los resultados obtenidos, invertir en infraestructuras de transporte y en innovación tecnológica mejora y mantiene los niveles de competitividad alcanzados en los países. Nuestros resultados, también apoyan la hipótesis de que los países comercian más cuanto más similares son desde un punto de vista tecnológico y que el desarrollo de las tecnologías de la información ha reducido el efecto negativo de la distancia geográfica sobre el comercio internacional.

Palabras clave: modelo de gravedad, tecnología, infraestructura, comercio internacional

1. Introduction

The aim of this research work is to analyse the relationship between trade, technological innovation and geography, within a desirable theoretical and empirical framework. Then we test empirically how technological innovation and geographical factors influence international trade.

A model that has been widely used to study the determinants of trade is the gravity model. Tinbergen (1962) and Pöyhönen (1963) were the first authors to apply the gravity equation to analyse international trade flows. Since then, the gravity model has become a popular instrument in empirical foreign trade analysis. The model has been successfully applied to flows of varying types such migration, foreign direct investment and, more specifically, to international trade flows. Gravity models can be augmented with additional variables that can foster or damage international trade, such as geographical, social, cultural, linguistic, integration and infrastructure variables.

To analyse how technological innovation transforms the geography of trade, the development of relevant indicators in a knowledge-based economy is needed. In this research work, we select two technology indices built from different variables in order to capture several aspects of the technological innovation process.[1]

The next section presents the theoretical model. In Section 3, the empirical model is estimated and the main results are shown. Regression diagnostics are also performed. Section 4 investigates the relationship between trade and income, where we analyse the possible endogeneity of trade and technological innovation and trade and income. Moreover, we evaluate the existence of reverse causality. Finally, in Section 5 a number of conclusions are presented.

2. Theory and model specification

In order to understand the role played by cross-country differences in relative factor endowments and relative country size in the determination of the volume of trade, we build a model based on Helpman and Krugman (1996). We outline the three cases developed by these authors and we introduce some variables in a more realistic framework with two differentiated goods in the market in order to obtain our final model, which supports the notion that comparative advantage determines international trade. We focus on some increasing production factors: tariff revenue, innovation, and

[1] *TAI* (UNDP, 2001) and *ArCo* (Archibugi and Coco, 2002).

"hard" and "soft" investment in infrastructure. However, the gains of increasing trade are attenuated by the resistance imposed by geographical barriers. Technology and innovation also determine countries' specialisation, trade flows and economic growth.

Case 1

TRADE VOLUMES IN A STANDARD TWO-COUNTRY, TWO-SECTOR, TWO-FACTOR, HECKSCHER-OHLIN-TYPE WORLD ECONOMY

According to Helpman and Krugman (1996), the volume of trade (*T*) can be defined as the sum of exports across countries:

$$\boldsymbol{T} = \boldsymbol{p}(\boldsymbol{X} - \boldsymbol{s}\overline{\boldsymbol{X}}) + (\boldsymbol{Y}^* - \boldsymbol{s}^*\overline{\boldsymbol{Y}}) \quad (1)$$

where X (X^*) and Y (Y^*) are the output of goods X and Y in the home country, which is a relatively capital-rich country (the foreign country, a relatively labour-rich country). The home country exports X (relatively capital-intensive goods) and imports Y (relatively labour-intensive goods), p is the price of X and Y is taken to be the numeraire. $\overline{X}$ is the output of goods X in the world economy ($\overline{\boldsymbol{X}} = \boldsymbol{X} + \boldsymbol{X}^*$) and $\overline{Y}$ is the output of goods Y in the world economy ($\overline{\boldsymbol{Y}} = \boldsymbol{Y} + \boldsymbol{Y}^*$). Finally, s (s^*) is the share of the home (foreign) country in world income and spending, hence $\boldsymbol{s} + \boldsymbol{s}^* = 1$, and $\boldsymbol{s} = \frac{\boldsymbol{Y} + \boldsymbol{pX}}{\overline{\boldsymbol{Y}} + \boldsymbol{p}\overline{\boldsymbol{X}}} = \frac{\boldsymbol{GDP}}{\overline{\boldsymbol{GDP}}}$. Implicit in equation (1) is the assumption that tastes are homothetic and identical across countries.

Assuming balanced trade, i.e. expenditure equals income, the authors arrive at the following equation:

$$\boldsymbol{T} = 2\boldsymbol{p}(\boldsymbol{X} - \boldsymbol{s}\overline{\boldsymbol{X}}) = 2(\boldsymbol{Y}^* - \boldsymbol{s}^*\overline{\boldsymbol{Y}}) \quad (2)$$

Helpman and Krugman (1996) show that the larger the volume of trade is, the larger the difference across countries in factor composition will be (capital (*K*) and labour (*L*)), thus implying that differences in factor composition determine trade and relative country size has no effect on the volume of trade.[2]

$$\boldsymbol{T} = \boldsymbol{F}(\boldsymbol{L},\boldsymbol{K}) \equiv g_{\boldsymbol{L}}\boldsymbol{L} + g_{\boldsymbol{K}}\boldsymbol{K} \tag{3}$$

Therefore, if $g_{\boldsymbol{L}} > 0$ and $g_{\boldsymbol{K}} < 0$, X is relatively labour intensive, and if $g_{\boldsymbol{L}} < 0$ and $g_{\boldsymbol{K}} > 0$, X is relatively capital intensive.

<u>Case 2</u>

SECTOR X PRODUCES DIFFERENTIATED PRODUCTS WITH INCREASING RETURNS TO SCALE

According to Helpman and Krugman (1996), with a sector producing differentiated goods (X, which is relatively capital intensive) both countries export varieties, but the home country is a net exporter of X and only the foreign country exports Y. Then, the volume of trade is,

$$\boldsymbol{T} = \boldsymbol{s}^{*}\boldsymbol{pX} + \boldsymbol{spX}^{*} + (\boldsymbol{Y}^{*} - \boldsymbol{s}^{*}\overline{\boldsymbol{Y}}) \tag{4}$$

where the first component represents exports of X by the home country (a share s^* of the output of the home country is exported to the foreign country), the second component represents exports of X by the foreign country (a share s of the output of the foreign country is exported to the home country), and the last component represents exports of the non-differentiated goods by the foreign country.

Assuming balanced trade, the authors arrive at the following expression,

$$\boldsymbol{T} = 2\boldsymbol{s}^{*}\boldsymbol{pX} = 2(\boldsymbol{spX}^{*} + \boldsymbol{Y}^{*} - \boldsymbol{s}^{*}\overline{\boldsymbol{Y}}) \tag{5}$$

[2] They let $\boldsymbol{s}^{\boldsymbol{j}}$ be the relative size of country j as measured by GDP, so $\boldsymbol{s}^{\boldsymbol{j}}$ is the share of country j in spending ($\boldsymbol{s}^{\boldsymbol{j}} = \frac{\boldsymbol{V}^{\boldsymbol{j}}}{\overline{\boldsymbol{V}}}$). Every country receives an endowment $\boldsymbol{V}^{\boldsymbol{j}} = (\boldsymbol{V}_1^{\boldsymbol{j}}, \boldsymbol{V}_2^{\boldsymbol{j}}, \ldots, \boldsymbol{V}_N^{\boldsymbol{j}})$ of factors of production, and $\overline{\boldsymbol{V}} = (\overline{\boldsymbol{V}}_1, \overline{\boldsymbol{V}}_2, \ldots, \overline{\boldsymbol{V}}_N)$ describes the available quantities of factors of production in the world economy. As X is a linear function of home country factor endowments, we have $\boldsymbol{L} = \boldsymbol{a}_{\boldsymbol{LY}}\boldsymbol{Y} + \boldsymbol{a}_{\boldsymbol{LX}}\boldsymbol{X}$ and $K = a_{KY}Y + a_{KX}X$, where $\boldsymbol{a}_{\boldsymbol{li}}$ are the factor inputs per unit output in the integrated equilibrium.

Equation (5) shows that an increase in production of *X* in the home country tends to foster the volume of trade, whereas a decline in the relative size of the foreign country (s^*) tends to decrease the volume of trade.

From equation (5), they obtain:

$$\hat{T} = \hat{s}^* + \hat{X} \qquad (6)$$

where "hats" denote proportional rates of change (e.g. $\hat{X} = \frac{dX}{X}$). The volume of trade is a function of changes in the output in sector *X* (differentiated goods) and a function of the size of each country,[3] as we can observe in equation (7):

$$\hat{T} = \hat{X}\,(1 - \frac{s}{s^*}) \qquad (7)$$

Reallocations that maintain relative country size constant but produce higher output in the sector *X* of the relatively capital-rich country (the home country) increase the volume of trade. Thus, for a given relative country size, the larger the volume of trade is, the larger the difference in relative factor endowments will be.

There is an important difference between the world economy with differentiated products (Case 2) and the standard Heckscher-Ohlin world economy with homogeneous products (Case 1). Whereas in Case 1, relative country size did not have an effect on the volume of trade, Case 2 introduces a major link between the volume of trade and relative country size.

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[3] $\hat{s}^* = \frac{dGDP^*}{GDP^*} = \frac{-dGDP}{GDP^*} = \frac{-G\hat{D}Ps}{s^*}$. That is why we have $s = \frac{GDP}{G\bar{D}P}$ and $s^* = \frac{GDP^*}{G\bar{D}P}$.

Then $\hat{s}^* = \frac{-G\hat{D}P \cdot \frac{GDP}{G\bar{D}P}}{\frac{GDP^*}{G\bar{D}P}} = \frac{-\frac{dGDP}{GDP} \cdot \frac{GDP}{G\bar{D}P}}{\frac{GDP^*}{G\bar{D}P}} = \frac{-dGDP}{GDP^*}$. As $G\hat{D}P = \hat{X}$, therefore

$\hat{T} = \hat{X}\,(1 - \frac{s}{s^*})$.

Case 3

A WORLD WITH TWO DIFFERENTIATED PRODUCTS

According to Helpman and Krugman (1996), in this case every country imports from its trading partner a fixed share of the output of every commodity,

$$T = s(X_1 * + pX_2 *) + s * (X_1 + pX_2) \quad (8)$$

where outputs of differentiated, relatively labour-intensive goods are denoted by X_1 and $X_1 *$. As ($X_1 * + pX_2 *$) is the whole output produced by the foreign country and ($X_1 + pX_2$) is the whole output produced by the home country, then:

$$T = sGDP * + s * GDP \quad (9)$$

Equation (9) implies that with a constant GDP and $GDP *$, the volume of trade depends only on relative country size, and the more equal the size of the countries is, the larger it will be, regardless of the composition of factor endowments.

Extended Case 3

Based on Helpman and Krugman (1996), we develop a theoretical framework which introduces some increasing production factors: tariff revenue, innovation, and "hard" and "soft" investment in infrastructure as determinants of the volume of trade. Geographical barriers, technology and innovation also determine countries' specialisation, trade flows and economic growth.

Following Deardorff (1995), Bougheas et al. (1999) and Eaton and Kortum (2002), we introduce transport costs following the Samuelson "iceberg" type (1954), where only a fraction $g = \frac{1}{t}$ of the quantity exported actually reaches the final destination and delivering a unit from the home to the foreign country requires production of more than a unit. Transport costs can be determined by geographical factors, since positive geographical barriers means that $t > 1$.

Additionally, Bougheas et al. (1999) point out that "there is a simple way to introduce infrastructure in the above model. If the role of 'hard' infrastructure is to improve transportation conditions we can think of it as a cost-reducing technology."[4] Therefore, we introduce transport infrastructure by reducing transport costs (t) and

[4] Bougheas et al., 1999, page 173.

increasing the fraction of the goods shipped that actually reaches the final destination. However, if one of the countries improves its transport infrastructure and the other does not improve it with the same intensity, g will change at a different rate. We therefore consider t as a measure of transport costs in the home country and t^* as a measure of transport costs in the foreign one.

According to Deardorff (1995), trade can be valued either exclusive of transport costs (f.o.b) or inclusive of transport costs (c.i.f) for export flows. This author claims that trade flows must be reduced by the amount of the transport costs on an f.o.b basis[5] and, hence, we assume that exports are sold at f.o.b prices and the greater part of transport costs are paid by the importer country.

We also include the "soft" infrastructure following Freund and Weinhold (2004). The authors include the effect of the Internet on trade in their model by assuming that the Internet reduces the fixed cost to enter a particular market and, as they point out, "the Internet is likely to reduce this type of entry cost since networks can expand and information can be more easily exchanged".[6] Hence, the richer the "soft" infrastructure is (which can be measured by Information and Communication Technology achievement – ICT – and innovation activity), the lower the fixed entry costs will be, and this effect can be reflected in the final price of goods (price changes from p to p' in the home country, being $p > p'$, and price changes from p to p'' in the foreign country, being $p > p''$) and the final price of goods changes their final demand and exports. We use b (b^*) to represent the increase in trade as a consequence of lower final prices in our model ($b \geq 1$ and $b^* \geq 1$).

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[5] When the author considers a case of impeded trade, with Cobb-Douglas preferences, on a c.i.f basis the author obtains $T_{ij}^{cif} = b_i Y_j = \frac{Y_i Y_j}{Y^w}$ and on an f.o.b basis the result is $T_{ij}^{fob} = \frac{Y_i Y_j}{t_{ij} Y^w}$, where T_{ij} is the value of exports from country i to country j, b_i is a fixed share of their incomes that consumers spend on the product of country i. Y_i and Y_j are i's and j's income, Y^w is world income and t_{ij} are transport costs. For the CES case, relative distance from suppliers is considered and, therefore, bilateral trade flows are centred around the same values found in the Cobb-Douglas case, although they are smaller for countries that are further apart than the average distance and larger for countries that are closer than the average.

[6] Freund and Weinhold, 2004, page 174.

As a further step, we take into account integration agreements across countries. Anderson and van Wincoop (2003) use a variable $\boldsymbol{b_{ij}}$ to reflect the existence of an international border between i and j. When $\boldsymbol{b_{ij}}$ = 1, regions i and j are located in the same country. Otherwise, $\boldsymbol{b_{ij}}$ takes the value one plus the tariff equivalent of the border barrier between the countries in which the regions are located. The authors use this variable to model unobservable trade costs. In our framework, we can consider a variable $I=I^*$ that takes a value of one when countries remove their barriers to trade or when they are integrated within the same economic area. When tariffs or non-tariff barriers deter trade because imports are burdened with taxes in the home country, we have $I > 1$, and when imports are burdened with taxes in the foreign country, we have $I^* > 1$; thus, there are positive entry costs involved in entering foreign countries.

Taking into account transport costs, infrastructure and integration variables, the specification of the model is:

$$\boldsymbol{T} = \boldsymbol{s}\boldsymbol{b}\,(\boldsymbol{X}_1 * + \boldsymbol{p}''\boldsymbol{X}_2 *)\frac{1}{t}\frac{1}{\boldsymbol{I}} + \boldsymbol{s}*\boldsymbol{b}*(\boldsymbol{X}_1 + \boldsymbol{p}'\boldsymbol{X}_2)\frac{1}{t*}\frac{1}{\boldsymbol{I}*} \qquad (10)$$

When we include the additional variables in equation (9) considered in Case 3, the new specification becomes:

$$T = s\,b\,GDP*\frac{1}{t\,I} + s*b*GDP\frac{1}{t*I*} \qquad (11)$$

In our model, b and $b*$ represent the increase in trade as a consequence of lower final prices for ICT achievement and innovation activity ($b \geq 1$ and $b* \geq 1$). An increase in these parameters will raise trade volumes.

Taking these considerations into account, since we have two differentiated goods, $\boldsymbol{X}_1$ and X_2, and both countries export varieties of these goods, we introduce b and $b*$ as endogenous variables depending on the level of innovation and other factors related to the advances in ICT which are achieved in each country,

$$b = \ln n + m + e$$

$$b* = \ln n * + m * + e * \qquad (12)$$

where n ($n*$) is the innovation level in the home (foreign) country and m ($m*$) includes other factors related to the advance in ICT in the home (foreign) country; thus both reduce the final prices of the goods. Moreover, b and $b*$ can foster trade due to the improved quality and greater variety of exported goods, so e (e^*) indicates other reasons that lower the final prices of the goods.

Rewriting equation (11), we obtain our final model, where we can see that trade increases more slowly when innovation is higher, since innovation is more relevant at its earlier stages and, whereas it could exceed the socially optimal level at a very advanced level (Gans and Stonecash, 2002).

$$\boldsymbol{T} = \boldsymbol{s}\boldsymbol{GDP}^* \frac{\ln n + m + e}{\boldsymbol{t}\,\boldsymbol{I}} + \boldsymbol{s}^*\boldsymbol{GDP} \frac{\ln n^* + m^* + e^*}{\boldsymbol{t}^*\boldsymbol{I}^*} \qquad (13)$$

In summary, geographical factors play an important role in the determination of transport costs. However, transport and entry costs can be modified by the *hardware* and *software* infrastructure. The latter depends on the level of innovation and other factors related to technological innovation, and on the advance in ICT in the countries.

The outlined model shows that if imports are burdened with taxes, there are positive costs of entering the market and hence international trade flows decrease. Finally, our model is not able to predict whether technology is altering the effect of distance and other geographical barriers on trade, and the impact of other geographical factors and social relations are not reflected either. In what follows we study these factors more deeply from an empirical point of view and from the theoretical model, expressed in log linear form, we will derive the estimated model.

3. Estimated equation and empirical results

3.1. Data, sources and variables

Table A.1 in appendix A[7] shows a summary of the data used in our analysis. With respect to technological and infrastructure variables, some additional explanations are needed. We have calculated values for TAI (the information is only available for the period 1997-2001) using the same criteria followed by the United Nations Development Programme. The classification obtained is slightly different to the *Human Development Report* classification for 2001 because we calculate the arithmetic averages for OECD member country indicators and then use them to fill the gaps of missing data for some OECD countries, thus increasing the sample size. Our first results can be summarised in

[7] Appendix A. Table A.1. The first column lists the variables used for empirical analysis, the second column outlines a description of the variables, and the third column shows the data sources.

a ranking[8] that includes five additional countries if we compare it with the United Nations Development Programme's ranking, these nations being Denmark, Iceland, Luxembourg, Switzerland and Turkey. These countries are OECD member countries and they increase our sample to 77 countries.[9] The countries are classified in four blocks as shown by the existence of a gap between the last country in one group and the first in the next group (see UNDP, 2001 and Archibugi and Coco, 2002).

Scores are derived as an index relative to the maximum and minimum achieved by countries in any indicator of its four dimensions: creation of technology, diffusion of recent innovations, diffusion of old innovations and human skills. The performance of each index takes a value between 0 and 1 calculated according to equation (14).

$$\boldsymbol{I}1 = \frac{(\boldsymbol{actual\ value} - \boldsymbol{observed}\ \min \boldsymbol{value})}{(\boldsymbol{observed}\ \max\ \boldsymbol{value} - \boldsymbol{observed}\ \min \boldsymbol{value})} \qquad (14)$$

The TAI is calculated as a simple average of the four dimension indices, based on the assumption that components play a comparable role in the technological achievement of a country. A second possible way to compute the composite index could be to apply equation (15),

$$\boldsymbol{I}2 = \frac{(\boldsymbol{actual\ value} - \boldsymbol{average\ value})}{\boldsymbol{st\,a\,ndar\ deviation}} \qquad (15)$$

Equation (14) is preferred since the use of equation (15) implies the loss of observations and a more difficult comparison among countries due to a higher number of negative values for the dimensions and, generally, a lower value for the TAI.

Transport infrastructure variables are calculated with data on kilometres of paved roads and kilometres of motorways per square kilometre, taking into account the quality of the roads. We use equation (16) to calculate the index.

$$\boldsymbol{Infrastructure\ \ v\,ariable} = \frac{((0.75 \cdot \boldsymbol{paved\ \ roads}(\boldsymbol{km})) + \boldsymbol{motorways}(\boldsymbol{km}))}{\boldsymbol{Land\ \ area}(\boldsymbol{km}^2)} \qquad (16)$$

[8] Appendix A. Table A.2. The three columns show the TAI ranking, the list of countries classified and the TAI value.

[9] In the empirical application, we use only 62 countries due to the existence of missing values for other variables different from TAI.

3.2. Main results

In order to evaluate the empirical effects of technological innovation and geographical factors on international trade, we derive a gravity model augmented with technological variables and a transport infrastructure index from equation (11). Integration dummies are added in order to analyse the impact of trade agreements on international trade. A number of dummies representing geographical and cultural characteristics are also added. The model is expressed in additive form using a logarithmic transformation. The estimated equation is:

$$\begin{aligned} \ln \boldsymbol{X_{ij}} = {} & a_0 + a_1 \cdot \ln \boldsymbol{Y_i} + a_2 \cdot \ln \boldsymbol{Y_j} + a_3 \cdot \ln \boldsymbol{P_i} + a_4 \cdot \ln \boldsymbol{P_j} + a_5 \cdot \boldsymbol{Adj_{ij}} + a_6 \cdot \boldsymbol{Isl} + a_7 \cdot \boldsymbol{Land} + \\ & + a_8 \cdot \boldsymbol{CACM} + a_9 \cdot \boldsymbol{CARIC} + a_{10} \cdot \boldsymbol{MERC} + a_{11} \cdot \boldsymbol{NAFTA} + a_{12} \cdot \boldsymbol{CAN} + a_{13} \cdot \boldsymbol{UE} + \\ & + a_{14} \cdot \ln \boldsymbol{Dist_{ij}} + a_{15} \cdot \boldsymbol{Lang_{ij}} + a_{16} \cdot \boldsymbol{TAI_i} + a_{17} \cdot \boldsymbol{TAI_j} + a_{18} \cdot \boldsymbol{Inf_i} + a_{19} \cdot \boldsymbol{Inf_j} + \boldsymbol{u_{ij}} \end{aligned} \qquad (17)$$

where *ln* denotes natural logarithms.

The model is estimated with data for 62 countries in 1999 and a total of 3782 (62*61) bilateral trade flows are obtained (Appendix B, Figure 1). The presence of missing/zero values in the bilateral trade flows data reduces the sample to 3126 observations. We perform OLS estimation on the double log specification as given by equation (17).

X_{ij} denotes the value of exports from country *i* to *j*, Y_i and P_i are income and population in the exporter's market, Y_j and P_j are income and population in the destination market, Adj_{ij} is a dummy that takes a value of 1 when countries share the same border and zero otherwise, *Isl* takes a value of 1 when the exporter or the importer are islands, *Land* is a dummy for *landlocked* countries, CACM is a dummy that takes a value of 1 when both countries belong to the Central American Common Market, CARIC is a dummy that takes a value of 1 when both countries belong to the Caribbean Community, MERC is a dummy that takes a value of 1 when both countries belong to Mercosur, NAFTA takes a value of 1 when countries are members of the North American Free Trade Area, CAN is a dummy representing Andean Nations Community members and UE takes a value of 1 when countries are members of the European Union. Since suitable direct measures of distance costs are unavailable, geographical distance between countries is often used as a proxy for transport costs in gravity equations, so $Dist_{ij}$ is the geographical great circle distance in kilometres between the capitals of country *i* and *j*. $Lang_{ij}$ is a dummy for countries sharing the same language, and TAI_i and TAI_j are technological variables measuring technological innovation in the exporter and the importer countries. Inf_i and Inf_j are infrastructure variables measuring the level of transport infrastructures in the exporter and the importer countries. Finally, u_{ij} is independently and identically distributed among countries.

In relation to our main results, Table 1 shows the baseline model and the contribution of the dimensions considered in the TAI to trade flows.

Model 1 presents the OLS results for the baseline case, which excludes technological and infrastructure variables. The coefficients on income are both positive, as expected, and the income elasticities are below one for the exporter and the importer. Higher income economies tend to be more interested in product differentiation and specialisation, and therefore they trade more. The coefficients on population are positive and significant – a higher market fosters trade, thus indicating the presence of economies of scale. Finally, the coefficient on distance has a negative sign, as expected, because lower distances imply lower transport costs and a higher amount of goods traded.

Model 2, 3, 4 and 5 estimate the variables considered in the augmented gravity model, although the technological innovation variable is broken down in its four dimensions: creation of technology, diffusion of recent innovations, diffusion of old innovations and human skills. These variables are significant and have the expected sign, however some differences in the magnitudes of the coefficients and in the significance of variables can be observed depending on the dimension included in the gravity equation. For example, income coefficients are higher when the creation of technology index is included, adjacency is not significant when the human skills is considered and some coefficients and signs on integration dummies are also different. We observe a higher explanatory power derived from the inclusion of technological variables for exporter countries than for importer countries and a higher variability of the bilateral export flows is explained when we include the diffusion of old innovations index as a proxy for technological innovation.

In order to determine the effect of investments on the four dimensions, we analyse the variability between the maximum and the minimum values of the indices. The variability in the indices is 61.9% for creation of technology, 79.35% for diffusion of recent innovations, 87.86% for diffusion of old innovations and 89.72% for human skills. Therefore, those countries that not arrive at a basic level of technological innovation should invest in old innovations and education. This seem a good alternative to foster international trade.

TABLE 1.
Determinants of international trade. Baseline model and augmented gravity model (technological innovation differentiated by 4 dimensions)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant term	-10.42*** (-11.94)	-10.84*** (-13.84)	-11.62*** (-17.64)	-22.8*** (-37.41)	-16.69*** (-26.49)
Exporter's income	0.27*** (13.22)	0.15*** (11.15)	0.08*** (8.75)	0.02** (2.16)	0.06*** (7.79)
Importer's income	0.22*** (11.47)	0.14*** (9.31)	0.09*** (7.34)	0.04*** (3.09)	0.07*** (6.38)
Exporter's population	0.70*** (23.08)	0.71*** (29.37)	0.77*** (39.42)	1.03*** (57.95)	0.94*** (48.66)
Importer's population	0.51*** (15.79)	0.53*** (21.36)	0.57*** (26.41)	0.77*** (37.38)	0.69*** (34.71)
Adjacency dummy	-	0.44** (2.36)	0.49*** (3.15)	0.37** (2.23)	0.17 (1.18)
Island dummy	-	-0.4*** (-3.58)	-0.27*** (-3.01)	-0.45*** (-5.32)	-0.23*** (-2.61)
Landlocked dummy	-	-1.08*** (-10.48)	-1.16*** (-13.47)	-0.75*** (-9.54)	-0.84*** (-10.21)
CACM dummy	-	0.93*** (2.89)	1.22*** (4.92)	2.38*** (9.96)	2.17*** (8.04)
CARICOM dummy	-	2.99*** (2.91)	4.44*** (4.65)	2.88*** (2.86)	4.37*** (4.65)
MERCOSUR dummy	-	2.52*** (8.56)	3.12*** (10.09)	1.74*** (5.54)	2.55*** (5.81)
NAFTA dummy	-	3.07*** (7.41)	0.47 (1.11)	1.42*** (2.96)	1.53*** (2.69)
CAN dummy	-	0.67 (1.4)	1.68*** (3.9)	0.71* (1.74)	0.76 (1.36)
UE dummy	-	0.51*** (4.33)	0.17* (1.75)	-0.05 (-0.53)	-0.17* (-1.66)
Distance	-1.38*** (-31.19)	-0.98*** (-20.82)	-0.97*** (-23.32)	-0.98*** (-26.53)	-1.12*** (-27.92)
Language dummy	-	0.67*** (6.12)	0.72*** (7.43)	0.88*** (10.58)	0.73*** (8.51)
Exporter's creation of technology	-	4.89*** (19.98)	-	-	-
Importer's creation of technology	-	3.04*** (10.59)	-	-	-
Exporter's diffusion of recent innovations	-	-	5.78*** (33.17)	-	-
Importer's diffusion of recent innovations	-	-	3.88*** (21.44)	-	-
Exporter's diffusion of old innovations	-	-	-	7.07*** (39.27)	-
Importer's diffusion of old innovations	-	-	-	4.95*** (30.38)	-
Exporter's human skills	-	-	-	-	6.46*** (41.31)
Importer's human skills	-	-	-	-	4.52*** (27.35)
Exporter's infrastructure	-	1.23*** (24.21)	0.82*** (17.18)	0.72*** (19.31)	1.03*** (26.6)
Importer's infrastructure	-	0.98*** (17.76)	0.72*** (13.9)	0.58*** (13.09)	0.83*** (17.99)
R-squared	0.407	0.637	0.719	0.786	0.761
Adjusted R-squared	0.406	0.634	0.717	0.785	0.759
S.E. of regression	2.511	1.971	1.733	1.511	1.598
Number of observations	3126	3126	3126	3126	3126

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$). Income, population and distance are also in natural logarithms. The estimation uses White's heteroscedasticity-consistent standard errors.

Model 1: *Baseline model;* ***Model 2:*** *Augmented gravity model. Contribution of the creation of technology dimension on trade;* ***Model 3:*** *Augmented gravity model. Contribution of the diffusion of recent innovations dimension on trade;* ***Model 4:*** *Augmented gravity model. Contribution of the diffusion of old innovations dimension on trade;* ***Model 5:*** *Augmented gravity model. Contribution of the human skills dimension on trade.*

Model 6, in Table 2, shows estimation results for equation (17). Income, population, geographical distance, technological innovation, transport infrastructure and all the dummies are significant and show the expected sign, excluding some integration dummies. Geographical variables are important determinants of international trade, therefore we have included other variables different to distance in order to analyse its effect on trade flows. The adjacency coefficient is expected to be positive since countries sharing a border trade more, and the landlocked coefficient is expected to be negative, since countries without direct access to the sea trade less. Moreover, we expect history, culture, language and social relations also to have important effects on trade. Language is included as a proxy for this type of relationship between countries. Its coefficient is expected to be positive. Integration dummies are also considered as social variables. Our results show that the European Union dummy has a negative sign. This result has also been found by other authors (e.g. Frankel et al., 1995; Cyrus, 2002) since an excessive regionalisation could lead to a permanent fragmentation of the world's trade rather than to a process of continuous integration. We find that this model has a high explanatory power given the high value of the R^2 (78.6%).

Model 8 shows estimation results for equation (17), but the technological variable included is the ArCo Index (Archibugi and Coco, 2002). Results are similar to those obtained in Model 6, but the magnitude of the estimated coefficient for TAI is higher than the estimated coefficient for ArCo. Both indicators are highly correlated (96%).

Models 7 and 9 include a new variable: technological distance between trading partners (Filippini and Molini, 2003). This is defined as the absolute difference between technological indicators in the exporter and the importer countries. This indicator is based on the insight that two countries can be far away from each other not only geographically, but also from a technological perspective. Technological gaps can deter trade since similar countries trade more. Therefore, we expect a negative correlation between this new variable and the export flows. Model 7 includes the technological distance measured by TAI, and Model 9 includes the technological distance measured by ArCo. Technological distance is significant in both models, increasing the explanatory power in the regressions. Our results support the view that countries tend to trade more when they are "closer" from a technological point of view. The explanatory power is lower for Models 8 and 9 than for Models 6 and 7.

TABLE 2.
Determinants of international trade. Augmented gravity model

Variable	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
Constant term	-15.38*** (-25.71)	-15.72*** (-27.04)	-19.24*** (-31)	-19.36*** (-32.05)	-14.37*** (-21.18)	-17.01*** (-24.41)
Exporter's income	0.02*** (2.62)	0.02** (2.53)	0.05*** (6.35)	0.04*** (5.69)	0.02** (2.34)	0.04*** (5.61)
Importer's income	0.04*** (3.72)	0.04*** (3.61)	0.06*** (5.21)	0.05*** (4.64)	0.04*** (3.51)	0.05*** (4.65)
Exporter's population	0.89*** (49.34)	0.89*** (51.41)	0.97*** (53.45)	0.98*** (55.1)	0.89*** (49.5)	0.98*** (53.6)
Importer's population	0.66*** (34.92)	0.67*** (35.64)	0.71*** (36.5)	0.72*** (37.46)	0.67*** (34.66)	0.72*** (36.43)
Adjacency dummy	0.43*** (2.89)	0.32** (2.15)	0.38** (2.34)	0.24 (1.52)	0.31** (2.03)	0.13 (0.8)
Island dummy	-0.46*** (-5.64)	-0.47*** (-5.77)	-0.27*** (-3.17)	-0.31*** (-3.72)	-0.46*** (-5.58)	-0.28*** (-3.26)
Landlocked dummy	-0.86*** (-11.34)	-0.83*** (-10.99)	-1.04*** (-13.82)	-0.97*** (-12.92)	-0.86*** (-11.29)	-1.02*** (-13.68)
CACM dummy	1.95*** (8.08)	1.99*** (8.56)	2.41*** (9.27)	2.39*** (9.55)	1.74*** (6.96)	1.95*** (7.22)
CARICOM dummy	4.29*** (4.49)	4.17*** (4.38)	4.07*** (4.03)	3.91*** (3.89)	4.24*** (4.44)	3.99*** (3.95)
MERCOSUR dummy	2.58*** (7.66)	2.49*** (7.73)	2.91*** (8.72)	2.76*** (8.5)	2.56*** (7.18)	2.85*** (7.62)
NAFTA dummy	0.71 (1.16)	0.83 (1.36)	1.12* (1.65)	1.2 (1.51)	0.81 (1.31)	1.31* (1.85)
CAN dummy	1.22*** (2.61)	1.05** (2.24)	1.06** (2.22)	0.89* (1.87)	1.26*** (2.69)	1.14** (2.4)
UE dummy	-0.24** (-2.54)	-0.35*** (-3.76)	-0.11 (-1.1)	-0.26** (-2.45)	-0.22** (-2.36)	-0.09 (-0.89)
Distance	-1*** (-26.72)	-0.95*** (-25.44)	-0.95*** (-24.82)	-0.91*** (-24.13)	-1.12*** (-20.55)	-1.2*** (-21.8)
Language dummy	0.92*** (11)	0.87*** (10.49)	0.91*** (10.41)	0.83*** (9.81)	0.93*** (11.16)	0.93*** (10.78)
Exporter's TAI	9.12*** (46.46)	9.17*** (47.61)	-	-	9.01*** (42.97)	-
Importer's TAI	6.39*** (30.7)	6.35*** (31.09)	-	-	6.2*** (27.19)	-
Technological distance (TAI)	-	-1.73*** (-9.43)	-	-	-	-
Exporter's ArCo	-	-	7.71*** (46.75)	8.04*** (48.74)	-	7.48*** (43.72)
Importer's ArCo	-	-	5.44*** (30.08)	5.68*** (32.69)	-	5.21*** (26.8)
Technological distance (ArCo)	-	-	-	-1.93*** (-11.61)	-	-
Exporter's infrastructure	0.68*** (17.65)	0.68*** (18.26)	0.91*** (25.06)	0.88*** (24.89)	0.67*** (17.34)	0.88*** (23.63)
Importer's infrastructure	0.57*** (12.57)	0.57*** (12.89)	0.74*** (17.45)	0.71*** (16.94)	0.56*** (12.31)	0.71*** (16.51)
LONGDISTi	-	-	-	-	0.21 (0.99)	0.59*** (2.75)
LONGDISTj	-	-	-	-	0.36 (1.53)	0.59** (2.52)
R-squared	0.788	0.793	0.781	0.789	0.788	0.783
Adjusted R-squared	0.786	0.792	0.779	0.788	0.786	0.782
S.E. of regression	1.506	1.484	1.529	1.499	1.505	1.522
Number of observations	3126	3126	3126	3126	3126	3126

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$). Income, population and distance are also in natural logarithms. The estimation uses White's heteroscedasticity-consistent standard errors.

Model 6: *Augmented gravity model (technological innovation measured by TAI);* ***Model 7:*** *Augmented gravity model and estimation of the effect of technological distance on trade (technological innovation measured by TAI)****; Model 8:*** *Augmented gravity model (technological innovation measured by ArCo);* ***Model 9:*** *Augmented gravity model and estimation of the effect of technological distance on trade (technological innovation measured by ArCo);* ***Model 10 and Model 11:*** *Augmented gravity model and estimation of the effect of information technology on geographical distance and therefore, on trade.*

The "beta coefficients" are calculated to determine the relative importance of different variables included in the augmented gravity model (see Table A.3, Appendix A). They are used by some researchers to compare the relative strength of the various predictors within the model and since the beta coefficients are all measured in standard deviations, instead of in variable units, they can be compared to one another.

The estimates of Model 6 imply that the highest beta coefficients are, in absolute value, for technological variables (0.504 for TAI in the exporter and 0.359 for TAI in the importer country), although the beta coefficient for population has also a considerable magnitude. On the one hand, this means that a standard deviation increase in the endowment of technological innovation in the exporter country would lead to a 0.504 standard deviation increase in the logarithm of exports. On the other hand, a standard deviation increase in the endowment of technological innovation in the importer country would explain a 0.359 standard deviation increase in the logarithm of bilateral exports. Clearly, this indicate that technological variables are important determinants on international trade flows.

Freund and Weinhold (2004) fail to show evidence of the role played by the Internet in altering the effect of geographical distance in trade patters. They construct a new variable (LONGDIST) which equals one if the distance between trade partners exceeds the average distance between all countries. Then, they interact it with the growth in the number of Internet hosts in each country. In order to compare our results with those obtained by these authors, we use the same methodology to create a similar variable. We interact LONGDIST with Internet hosts in each country. Our results do not show evidence that Internet use is altering the role of distance on trade, supporting the view of Freund and Weinhold (2004). However, it could be that a more general proxy for technological innovation would be better to measure this effect. In Model 10, we analyse whether technology has an effect on geographical distance. We interact TAI and LONGDIST, obtaining *LONGDISTi* *(LONGDIST*TAI_i)* and *LONGDISTj* *(LONGDIST*TAI_j)*. If technology and the advance of information and knowledge have reduced (increased) the impact of distance on trade, then the coefficient on the interaction term should be positive (negative). However, these coefficients are positive but non-significant.

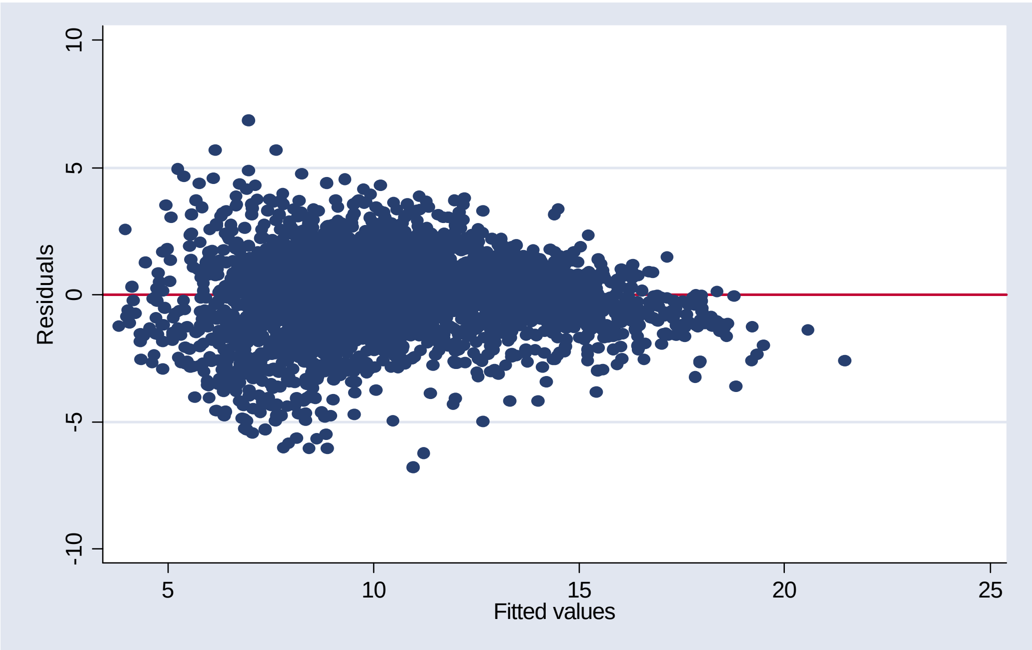
Finally, we use ArCo instead of TAI in Model 11 to analyse the effect of the knowledge-based economies on trade *(LONGDISTi* and *LONGDISTj* are composed with TAI_i and TAI_j). Since the coefficient of *LONGDISTi* and *LONGDISTj* are both positive and significant, our results offer some evidence showing that the information and knowledge advances have reduced the effect of distance on trade.

3.3. *Regression diagnostics*

In order to investigate the presence of multicollinearity, we build a correlation matrix among all the explanatory variables included in the model and we do not find any significant relations among them. The simple correlation coefficients are always below 60%. Moreover, we obtain the *variance inflation factor* (VIF). Tolerance, defined as 1/VIF is used to check for the degree of collinearity. A tolerance value lower than 0.1 means that the variable could be considered as a linear combination of other independent variables. The tolerance values for variables used in our gravity model are always higher than 0.1.

One of the main assumptions in ordinary least square regression is the homogeneity of variance of the residuals. If the variance of the residuals is non-constant, the residual variance is heteroscedastic. White's Test and the Breusch-Pagan/Cook-Weisberg Test indicate the presence of heteroscedasticity in the data. Moreover, in Graph 1 we use a graphical method to detect heteroscedasticity, where the residuals versus the predicted values are plotted. This graph shows that the pattern of the data points gets narrower towards the right end, which is an indication of heteroscedasticity. Therefore, all the equations in this research work are estimated using White's transformation to obtain consistent standard errors in the regressions.

GRAPH 1

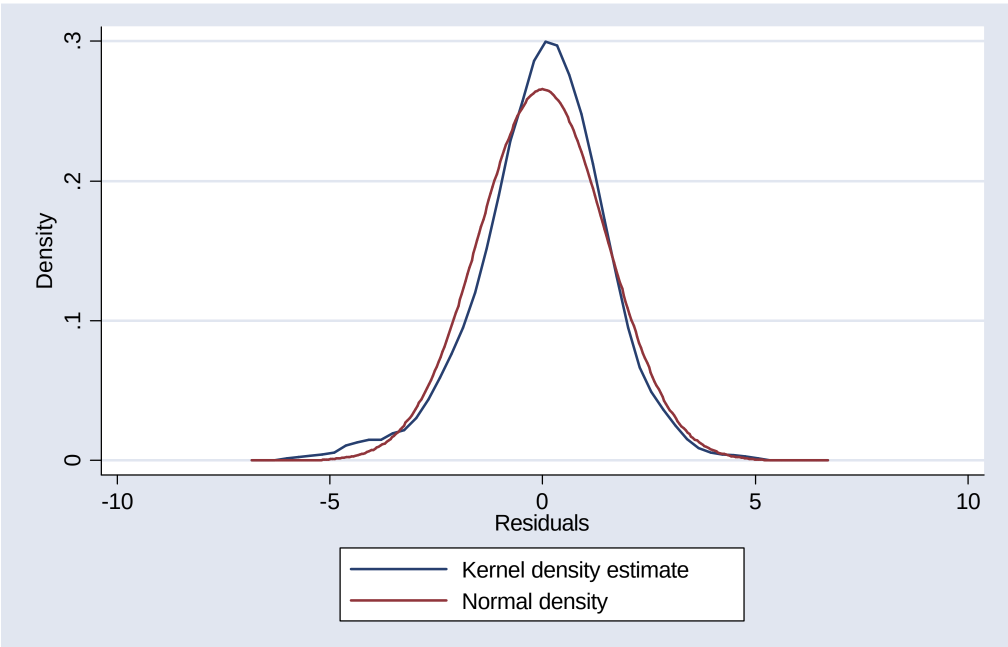


In order to check for the normality of the residuals, we compare the predicted residuals and the Kernel density estimates (Graph 2). Graph 3 shows skewness, kurtosis values and the Jarque-Bera statistic. Jarque-Bera is a statistical test for verifying whether the series are distributed normally. The test statistic measures the difference between the skewness and kurtosis of the series and those from the normal distribution. The null hypothesis is a normal distribution and the reported probability is the probability that a Jarque-Bera statistic exceeds (in absolute value) the observed value under the null hypothesis. Therefore, a small probability value leads to the rejection of the null hypothesis of a normal distribution.

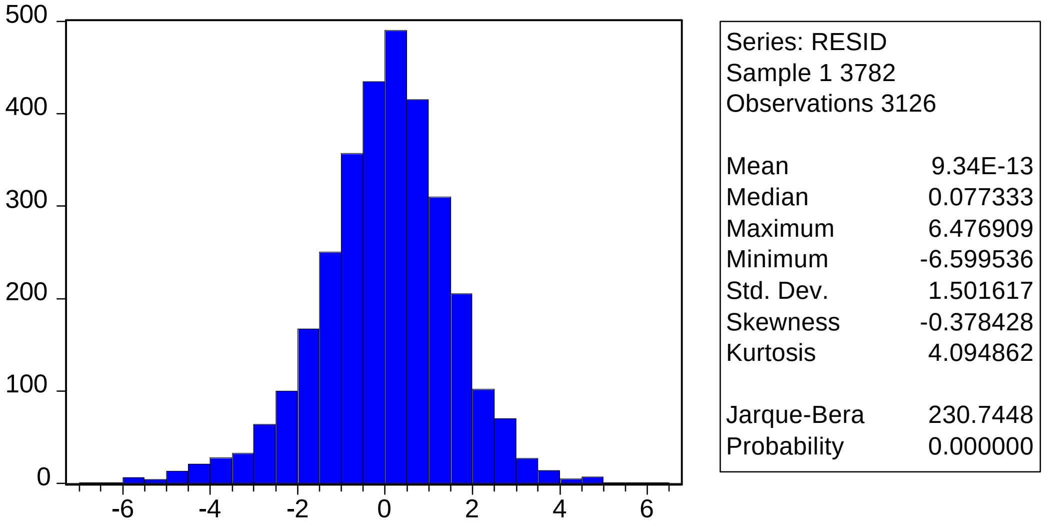
The results show a deviation from normality. However, normality of the residuals is only required for valid hypothesis testing, that is, the normality assumption ensures that the p-values for the t-test and F-test will be valid. Normality is not required in order to obtain unbiased estimates of the regression coefficients. OLS regression merely requires that the residuals must be distributed identically and independently.

Finally, we check for the model specification. A model specification error may occur when one or more relevant variables are omitted from the model, or one or more irrelevant variables are included in the model. Model specification errors can substantially affect the estimated coefficients of regression. We use the *linktest* command in STATA and the Ramsey test to test for specification errors.

GRAPH 2



GRAPH 3



The *linktest* is based on the idea that if a regression is properly specified, 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. The latter should not because, if our model is correctly specified, the squared predictions should not have much explanatory power.

In a first step, we calculate the *linktest* for the baseline case of the gravity model, where only distance, exporter's and importer's income, and exporter's and importer's population are included as independent variables. In this case, the variable of prediction is not significant (_hat) and the variable of square prediction is significant (_hatsq). Moreover, the hypothesis that the model has no omitted variables is rejected with the Ramsey RESET test (a regression specification error test for omitted variables). In our augmented gravity model, both the variable of prediction (_hat) and the variable of square prediction (_hatsq) are significant. Additionally, 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.

4. Trade and income

Although gravity models are in most cases estimated using ordinary least squares (OLS), this specification does not account for the existence of causality between income and/or technological innovation and trade. Since this is a potential problem that will lead to misspecification of the estimated model, in this section we analyse the possible endogeneity of technology and income variables in the gravity equation. In this case, income and/or technological innovation will be correlated with the error term and the OLS estimates would be biased and inconsistent.

Lachenmaier and Woessmann (2004) test empirically whether innovation causes exports using a micro-dataset. They argue that certain impulses lead firms to innovate and that certain obstacles that prevent firms from innovating can be considered as exogenous to the error term of the export equation. These authors find a statistically significant causal effect of innovation on exports.

Wong (2004) distinguishes the effects of trade and telephone call traffic on income. Since both trade and telephone traffic may be endogenous, they instrument trade with geographical variables and the pattern of interactions with colonial variables. Results show that the model produces good instruments for both variables.

In order to test for the presence of endogeneity, a Hausman test is performed for the coefficients and regressions. The purpose of this test is to indicate whether there is correlation between the regressors (income and technological innovation) and the error term in the augmented gravity model. The null hypothesis is that there is no correlation and therefore 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 and income in countries, but not with the error term of equation (17) will be desirable. We have selected total labour force in 1999 and land area in square kilometres as instruments for income, and average research and development expenditure (% of GDP) and average public spending on education (% of GDP) in the period 1994-1998 as instruments for technological innovation. The selection of the instrumental variables is based on Eaton and Kortum (1997). 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, thus improving productivity and income in countries. Moreover, we use the land area as an instrument for income, since some authors have shown that within-country trade increases income in countries (e.g. Frankel and Romer, 1999).

We also apply another version of the Hausman test to validate our results. This version is proposed by Davidson and MacKinnon (1993), who carried out the test by running an auxiliary regression. We estimate four OLS regressions. In a first step, we regress technological innovation (TAI_i) and income ($logY_i$) measures on all exogenous variables and an instrument (since the selected instruments for income and technology are highly correlated) to obtain the residuals. Then, in a second step, we estimate our augmented gravity model including the residuals from the first regressions as an additional variable. The result differs depending on the instrument included. When labour force is included as an instrument for income and R&D expenditure is used for technological innovation, the residuals of those regressions are not significant in the augmented gravity model.

Since the coefficients on the first stage residuals are not significantly different from zero for labour force and R&D expenditure, the test indicates that there is no endogeneity problem and, therefore, the OLS estimation is consistent. However, when land area is included as an instrument for income and public spending on education for technological innovation, the residuals of those regressions are significant in the augmented gravity model. Therefore, when land area and public spending on education are included as instruments, the test accepts the hypothesis of endogeneity.

Finally, we determine whether the instrumental variables chosen are valid. The first requirement of good instruments is that they must be highly correlated with the variable for which they are instrumenting. Table 3 shows that both land area and labour force are significant for income, and that the research and development expenditure and the public spending on education are highly significant in explaining technological innovation.

TABLE 3.
First Stage Regression

Variable	Model 3.A		Model 3.B	
Constant term	20.60*** (19.36)	22.33*** (69.04)	0.28*** (118.01)	0.21*** (17.55)
Labour force	0.29*** (4.25)	-	-	-
Land area	-	0.24*** (8.25)	-	-
Research and development expenditure	-	-	0.14*** (85.26)	-
Public spending on education	-	-	-	0.04*** (14.52)
R-squared	0.027	0.027	0.761	0.122
Adjusted R-squared	0.026	0.026	0.761	0.122
S.E. of regression	2.757	2.778	0.075	0.172
Number of observations	3782	3721	2867	3782

Notes: ***, **, *, indicate significance at 1%, 5% and 10%, respectively. T-statistics are in brackets. The dependent variable in Model 3.A is the exporter's income in natural logarithms, and the exporter's technological innovation in Model 3.B. Labour force and land area variables are also given in natural logarithms. 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, we regress the residual of the OLS regression on the instruments. The results show that the instruments used independently are indeed correlated with the error term (except labour force). This will in fact indicate 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. Our results show that the variables used as instruments for income and technology have a low explanatory power (all instruments have a lower R-squared than 0.0063) in the error term regressions.

Finally, since some of the results from the test accept the hypothesis of endogeneity, equation (17) has also been estimated by IV. Equation (17) has been estimated by OLS in the first column of Table 4 and by IV in the second and third columns, where income and technological innovation are considered respectively as endogenous. In the IV estimates, we observe several differences from the OLS coefficients. In Model 4.B, where income is considered as endogenous, exporter's income has a higher magnitude than by OLS and in Model 4.C, where technological innovation is considered as endogenous, the NAFTA dummy is significant and the UE dummy is not.

The main focus of the empirical application of this research was to analyse the influence of geographical factors and technological innovation on international trade flows. Nevertheless, we also devote some attention to the evaluation of the existence of reverse causality between trade and income. In this line of research, we find a large amount of literature dedicated to the study of the causality between trade and income and the magnitude of the impact. In the recent past, several authors have focused on the endogeneity problem created by including trade variables in income regressions. For example, Frankel and Romer (1999) introduce the use of instrumental variables in order to estimate the effect of trade on income. They used geographical variables as instruments for countries' trade shares, arguing that these variables have important effects on trade but are uncorrelated with other determinants of income. They estimate an income equation for 1985[10] by OLS and IV in order to prove that an increase in trade shares fosters income. The authors show that when trade shares are treated as endogenous, the coefficient on trade rises sharply.

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[10] $\ln \boldsymbol{Y_i} = \boldsymbol{a} + \boldsymbol{bT_i} + \boldsymbol{cN_i} + \boldsymbol{dA_i} + \boldsymbol{u_i}$, where Y_i is income per person in country i, T_i is the trade share (measured by the ratio of imports plus exports to GDP), N_i and A_i are population and area, respectively.

TABLE 4.
Instrumenting for income and technological innovation

Variable	Model 4.A	Model 4.B	Model 4.C
Constant term	-15.38***	-19.54***	-15.12***
	(-25.71)	(-14.32)	(-23.37)
Exporter's income	0.02***	0.25***	0.02***
	(2.62)	(3.52)	(2.76)
Importer's income	0.04***	0.05***	0.04***
	(3.72)	(4.13)	(3.81)
Exporter's population	0.89***	0.86***	0.84***
	(49.34)	(25.56)	(43.72)
Importer's population	0.66***	0.66***	0.66***
	(34.92)	(33.51)	(33)
Adjacency dummy	0.43***	0.35**	0.39***
	(2.89)	(2.29)	(2.73)
Island dummy	-0.46***	-0.15	-0.34***
	(-5.64)	(-1.63)	(-3.76)
Landlocked dummy	-0.86***	-0.81***	-0.73***
	(-11.34)	(10.11)	(-8.94)
CACM dummy	1.95***	2.06***	2.01***
	(8.08)	(8.41)	(6.39)
CARICOM dummy	4.29***	4.43***	5.36***
	(4.49)	(4.54)	(35.09)
MERCOSUR dummy	2.58***	2.41***	2.52***
	(7.66)	(6.93)	(6.24)
NAFTA dummy	0.71	0.48	0.92*
	(1.16)	(0.83)	(1.69)
CAN dummy	1.22***	1.08**	1.12**
	(2.61)	(2.55)	(2.36)
UE dummy	-0.24**	-0.26***	-0.02
	(-2.54)	(-2.68)	(-0.24)
Distance	-1***	-1.08***	-0.9***
	(-26.72)	(-27.89)	(-23.09)
Language dummy	0.92***	0.77***	0.99***
	(11)	(8.65)	(10.71)
Exporter's TAI	9.12***	7.35***	8.11***
	(46.46)	(12.69)	(30.07)
Importer's TAI	6.39***	6.32***	6.64***
	(30.7)	(28.21)	(29.77)
Exporter's infrastructure	0.68***	0.63***	0.69***
	(17.65)	(16.37)	(17.69)
Importer's infrastructure	0.57***	0.56***	0.47***
	(12.57)	(11.75)	(9.83)
R-squared	0.788	0.763	0.786
Adjusted R-squared	0.786	0.761	0.785
S.E. of regression	1.506	1.595	1.417
Number of observations	3126	3067	2481

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$). Income, population and distance are also in natural logarithms. The estimation uses White's heteroscedasticity-consistent standard errors.

Income instruments: Total labour force in the exporter country in 1999 (in logarithms) and land area in square kilometres in the exporter country (in logarithms). **Technology instruments**: Average research and development expenditure (% of GDP) and the average public spending on education (% of GDP) over the period 1994-1998.

In this line, we analyse the effects of trade on income by estimating an income equation given by,

$$\ln \boldsymbol{Y_T} = \boldsymbol{a}_0 + \boldsymbol{a}_1 \ln \boldsymbol{X_{ij}} + \boldsymbol{a}_2 \ln \boldsymbol{P_i} + \boldsymbol{a}_3 \ln \boldsymbol{P_j} + \boldsymbol{a}_4 \ln \boldsymbol{LA_i} + \boldsymbol{a}_5 \ln \boldsymbol{LA_j} + \boldsymbol{u_{ij}} \qquad (18)$$

where Y_T is total income in countries *i* and *j*, X_{ij} is bilateral exports from country *i* to country *j*, P_i and P_j denote population in countries *i* and *j* respectively and LA_i and LA_j denote land area in countries *i* and *j* respectively.

We estimate equation (18) by OLS and IV. All the exogenous variables included in the gravity equation (17), except population, are used as instruments for bilateral trade. The results show that all the explanatory variables in the income equation are significant and have the expected sign (see Table 5). In both estimations, higher bilateral trade between countries implies higher total income, and the larger countries *i* and *j* are (as measured by land area), the higher total income is. The coefficient of bilateral trade is lower by OLS, meaning that the OLS coefficient of trade is understating the effect of trade on income. This result has also been found by Frankel and Romer (1999) and Irwin and Terviö (2002).

TABLE 5.
Determinants of total income

Variable	OLS	IV
Constant term	50.94*** (25.14)	52.27*** (25.42)
Bilateral trade	0.53*** (22.37)	0.66*** (22.88)
Exporter's population	-0.51*** (-4.44)	-0.64*** (-5.33)
Importer's population	-0.34*** (-2.99)	-0.41*** (-3.64)
Exporter's land area	0.36*** (7.58)	0.41*** (7.35)
Importer's land area	0.33*** (6.83)	0.34*** (6.16)
R-squared	0.168	0.161
Adjusted R-squared	0.167	0.159
S.E. of regression	3.759	3.776
Number of observations	3010	3010

Notes: ***, **, *, indicate significance at 1%, 5% and 10%, respectively. T-statistics are in brackets. The dependent variable is the sum of GDP in country *i* and *j* in natural logarithms (PPP, current international $). Population and land area are also in natural logarithms. The estimation uses White's heteroscedasticity-consistent standard errors. The data are for 1999.

5. Conclusions

In this research, we estimate a gravity equation augmented with technological innovation and transport infrastructure variables in order to analyse the impact of these variables on trade. Geographical (distance, adjacency, being an island and being landlocked) and social variables (integration, preferential agreements among countries and sharing a language) are also considered.

In the main empirical model applied in this research work, all the variables included have the expected sign and are significant, excluding some integration variables. We show that distance has a considerably low explanatory power on trade compared with transport infrastructure and technological innovation. Importers' technology has a lower effect on trade than exporters' technology and a higher technology endowment in the exporter country leads to greater exports. Moreover, our results support the hypothesis that countries tend to trade more when they are "closer" from a technological point of view.

According to our results, investing in transport infrastructure and technological innovation leads to the improvement and maintenance of the level of competitiveness. These variables can be considered as a barrier to trade for countries with lower endowment levels and, therefore, investing in them increases the participation of the poorest economies in the world economy.

We also analyse whether technology has any effect on geographical distance in a more globalised and integrated world. The results indicate that the development of information technology has lowered the effect of distance on trade, since the development of technological innovation means that long distances are less important nowadays than in the past.

In order to account for reverse causality, we estimate an income equation showing that trade, and countries' size, are important determinants of income. We estimate the income equation by OLS and IV. The OLS coefficient of trade is lower than the one obtained when trade is considered as being endogenous.

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APPENDIX A

TABLE A.1.
Variable descriptions and sources of data

Variable	Description	Source
X_{ij} : Exports from i to j	Nominal value of bilateral exports	Statistics Canada (2001)
Y_i : Exporter's income	Exporter's GDP, PPP (current international $)	World Bank (2001)
Y_j : Importer's income	Importer's GDP, PPP (current international $)	World Bank (2001)
P_i : Exporter's population	Total population in the exporter's market	World Bank (2001)
P_j : Importer's population	Total population in the importer's market	World Bank (2001)
Adj_{ij} : Adjacency dummy	Dummy variable = 1 if the trading partners share a border, 0 otherwise	CIA (2003)
Isl_i : Island dummy	Dummy variable = 1 if the exporter country is an island, 0 otherwise	CIA (2003)
$Land_{ij}$: Landlocked dummy	Dummy variable = 1 if the country is landlocked, 0 otherwise	CIA (2003)
CACM dummy	Dummy variable = 1 if the trading partners are members of CACM, 0 otherwise	Foreign Trade Information System (2003)
CARICOM dummy	Dummy variable = 1 if the trading partners are members of CARICOM, 0 otherwise	Foreign Trade Information System (2003)
MERCOSUR dummy	Dummy variable = 1 if the trading partners are members of MERCOSUR, 0 otherwise	Foreign Trade Information System (2003)
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	Foreign Trade Information System (2003)
UE dummy	Dummy variable = 1 if the trading partners are members of European Union, 0 otherwise	
$Dist_{ij}$: Distance	Great circle distances between country capitals of trading partners (km)	Great circle distances between cities (2003)
$Lang_{ij}$: Language dummy	Dummy variable = 1 if the trading partners share the same official language, 0 otherwise.	CIA (2003)
TAI_i : Exporter's TAI	Technological variable	UNDP (2001), author's calculations
TAI_j : Importer's TAI	Technological variable	UNDP (2001), author's calculations
$ArCo_i$: Exporter's ArCo	Technological variable	Archibugi and Coco (2002)
$ArCo_j$: Importer's ArCo	Technological variable	Archibugi and Coco (2002)
Inf_i : Exporter's infrastructure	Transport infrastructure variable	CIA (2003), authors' calculations
Inf_j : Importer's infrastructure	Transport infrastructure variable	CIA (2003), authors' calculations

Note: UNDP denotes United Nations Development Programme and CIA denotes Central Intelligence Agency.

TABLE A.2.
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:

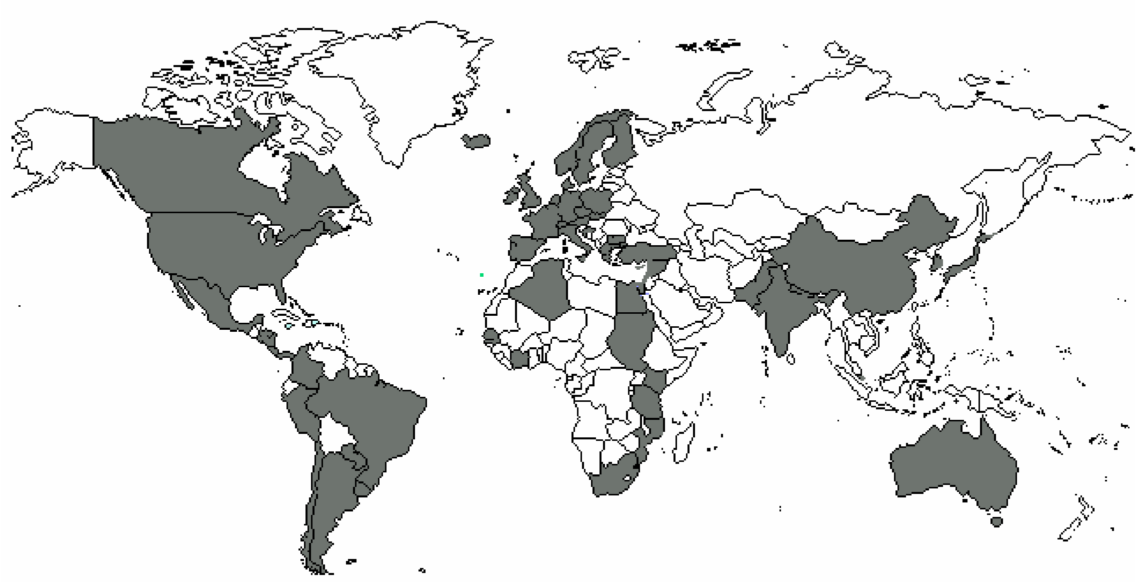
Technological Leaders (above 0.5). This group includes countries with a high capability to create and sustain technological innovation.
Potential Technological Leaders (from 0.35 to 0.49). This group includes countries that have invested in all four dimensions, but have been less innovative.
Dynamic Technological Adopters (from 0.19 to 0.34). Countries in this group try to achieve growth in their technology content and in 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 to low income levels. The relative position is not particularly meaningful due to the lack of adequate data.

TABLE A.3.
"Beta coefficients" of the variables included in the augmented gravity model

	Beta Coefficient
Exporter's income	0.0183443
Importer's income	0.0385702
Exporter's population	0.4261248
Importer's population	0.3156517
Adjacency dummy	0.0245367
Island dummy	-0.0533542
Landlocked dummy	-0.0967349
CACM dummy	0.0370647
CARICOM dummy	0.0333055
MERCOSUR dummy	0.0489882
NAFTA dummy	0.0095025
CAN dummy	0.0094735
UE dummy	-0.0172897
Distance	-0.2706165
Language dummy	0.1000771
Exporter's TAI	0.5036714
Importer's TAI	0.359052
Exporter's infrastructure	0.1562054
Importer's infrastructure	0.1290454

APPENDIX B

FIGURE 1.
Selected countries



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