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Technology trade in economic development

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Technology trade in economic development

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ABSTRACT

Recent evidence on the respective contributions of institutions and trade to income levels across countries has demonstrated that – once endogeneity is considered – institutional quality clearly dominates the effect of trade. We argue that overall trade is not the most appropriate measure for technology diffusion as a source of productivity growth and propose to focus on imports of research and development (R&D) intensive goods instead. Overall, we confirm previous findings that institutions matter most and that overall trade is not positively associated with per-capita income levels. Yet this does not hold for technology trade, as there is a positive and significant linkage between technology imports and income levels. This outcome is robust to various model specifications, including an instrumental variable approach.

Keywords: Growth, Technology Diffusion, Trade, R&D Spillovers.

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1. INTRODUCTION

Income per worker in the five richest economies is on average 64 times higher than in the five poorest nations.[1] Almost certainly, there are few questions that are of higher importance to development economics as to ask which factors contribute to this enormous gap. A prominent strand of the literature believes that per-capita income differences are mainly driven by differences in technology, which affect the productivity of capital and workers (Romer, 1993; Prescott, 1998). In fact, recent development accounting studies document large total factor productivity disparities across countries (Klenow and Rodríguez-Clare, 1997; Hall and Jones, 1999; Caselli and Coleman, 2006; Caselli, 2005).

While these studies are useful to measure the effects of productivity differences, they do not shed light on the identification of the *deep* determinants that explain differences in international productivity levels. Addressing this important research topic, recent studies have emphasised three mutually related causal factors: (1) geography as a relevant determinant of climate, natural resources endowments, morbidity rates and natural barriers to interact with other economies (Diamond, 1997; Gallup et al., 1999; Sachs, 2001); (2) openness to international trade as a channel of technology diffusion and the gains through exchange and specialisation (Frankel and Romer, 1999; Dollar and Kraay, 2002; Irwin and Terviö, 2002; Noguer and Siscart, 2004);[2] and (3) institutions as the rules and norms prevailing in a society that shape an individual's productive behaviour (North, 1990; Hall and Jones, 1999; Acemoglu et al., 2001; Rodrik et al., 2004).

These three determinants ultimately exert a fundamental influence on the well-known channels that promote economic growth: factor accumulation and technological progress. Finding the relative importance of each factor is a task that involves the

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[1] Figures relate to Gross National Income (GNI) per capita at purchasing power parity in current international US dollars in 2003 (World Bank, 2005).
[2] Integration has been exploited in dynamic models as a vehicle for knowledge spillovers. Key references are Rivera-Batiz and Romer (1991ab), Grossman and Helpman (1991), Barro and Sala-i-Martin (1995), Aghion and Howitt (1998), and Eaton and Kortum (1999).

treatment of endogeneity of openness and institutions, since geography is the only exogenous determinant. More open economies may induce higher growth rates and vice versa; institutional quality may have an impact on income levels, but richer economies may also have a preference for better institutions.

So far, only Rodrik et al. (2004) have attempted to estimate the relative relevance of each deep determinant of economic development, sorting out a complex web of causalities and employing a set of historical and geographical instruments that has been developed in recent cross-sectional growth empirics. In particular, they use the Frankel and Romer (1999) geographic instrument to estimate the effect of actual trade, and historical variables, such as the fraction of population that speaks English or another major European language as a mother tongue (Hall and Jones, 1999) or the mortality rates of colonial settlers, to estimate the effect of institutional quality (Acemoglu et al., 2001). Once endogeneity is taken into account, they find that trade openness does not have a significant influence on income levels, and conclude the primacy of institutions over the other factors.

In this paper, we argue that the total volume of trade as a measure of exposure to foreign technologies as an important source of productivity gains is not the most appropriate one. Rather, we focus on imports of research and development (R&D) intensive capital goods to capture technology diffusion. In growth models without spillovers and where new technologies arise in new vintages of capital goods (Greenwood et al., 1997), trade gives access to foreign goods and implicitly to embodied technologies. In this case, trade in R&D intensive goods brings about some benefits in the form of an increase in capital good's efficiency. Moreover, in endogenous growth models with knowledge spillovers (Rivera-Batiz and Romer, 1991ab; Grossman and Helpman, 1991) trade in differentiated capital goods raises capital efficiency and total factor productivity through learning and imitation.

We rely on the fact that worldwide R&D activities are concentrated in a handful of (OECD) countries that are the major producers and exporters of capital goods (Coe and Helpman, 1995; Eaton and Kortum, 2001) and consequently, import of R&D intensive goods is a reasonable proxy for investment in embodied technologies. Additionally, there is evidence that economies derive significant benefits in terms of five-year productivity growth rates from R&D performed by OECD countries importing machinery and equipment (Coe et al., 1997; Keller, 1998, 2000; Engelbrecht, 2002; Barrio-Castro et al., 2002). This supports the view that imports of certain goods contribute to technology diffusion through spillovers, at least in the mid-term[3].

In sum, both endogenous growth models and empirical evidence suggest that imports of R&D intensive goods rather than overall trade act as the main channel of technology diffusion. Under this view, it should be observed that countries adopting less technology through trade have a lower productivity level. Consequently, the estimation exercise involves the disentanglement of the different determinants and their relative impact on income levels, isolating changes in income levels and changes in institutions, overall trade and technology trade that arise from changes in geography and history. To facilitate a comparison of the empirical results, we closely follow the approach by Rodrik et al. (2004) and use the same exogenous variables to instrument for total trade and institutions, respectively. Similar to the Frankel-Romer approach, we construct an instrument for technology imports that is based on geographical information only.

Technology imports and total trade, however, are highly correlated: countries that trade more also import more technology. In general, both types of bilateral trade are based on the idea that countries trade different amounts because they face different prices. For instance, distance, as a proxy for transport cost, affects prices of different goods in a similar way, thereby making it difficult to assess the independent contribution of each trade channel to income levels. Nevertheless, the estimation of the effect of technology imports on income may be isolated from the overall price effect by simply taking into consideration that countries may import more capital goods because they have different abilities to make use of them. These advantages come in the form of abundance of skilled workers or an efficient economic environment. Eaton and Kortum (2001) find

[3] Using imports of total manufactures or other aggregates, Coe et al. (1997) find that there is still evidence of R&D spillovers but the results are not as strong as in comparison to a more restricted set of high-technology goods.

that geographic barriers to trade in equipment explain a high percentage of international differences in productivity due to variations in relative prices of equipment once a country's ability to make use of technologies is controlled with fixed effects. Also, Caselli and Wilson (2004) show that large differences in investment composition across countries (measured by imports of different capital goods) are based on each equipment type's degree of complementarity with other factors whose relative abundance is country specific.

In effect, we simultaneously estimate the effects of technology imports, overall trade, institutions, and geography on per-capita income using appropriate instruments for each of the three variables. Like Rodrik et al. (2004), we find that institutions clearly dominate over trade and geography in the income equation. Yet we show that technology imports have a positive impact on per-capita income levels and that this outcome is robust to various robustness checks. In addition, we use this framework to study the channels through which technology imports affect per-capita income levels. Breaking down output per worker into components, we evaluate the extent to which technology imports contribute to capital depth, human capital and total factor productivity differences. Once controlling for endogeneity, we find that technology diffusion through imports accounts for much of the variations in technological levels across countries.

In a preceding paper on the role of capital goods imports on economic growth, Lee (1995) presents a model in which the greater use of imported inputs increases the efficiency of capital accumulation, spurring long-term growth. In an instrumental variable regression, he shows that capital goods imports and growth rates are positively associated. However, his instruments are based on a mixture of geography (distance to trade partners and area) and policy variables (tariff rates). Whereas the former are exogenous the latter may not be.[4] We differ from Lee (1995) in three aspects: first, we do not simply use capital goods but rather, a broader definition that is more consistent with economic theory, that is, R&D intensive products; second, we employ only geographic information on imports to construct the instrumental variable; and third, we estimate a productivity equation in levels to examine the impact on (very) long-run growth rates.

The paper is structured as follows: In Section 2, we develop an instrument for technology trade. While Section 3 introduces the econometric specification and provides information on the variables used, Section 4 presents the estimation results for the income equation. Based on that, the analysis of the channels through which technology imports affect productivity levels can be found in Section 5. Finally, the paper ends with some concluding remarks in Section 6.

2. AN INSTRUMENT FOR TECHNOLOGY IMPORTS

Before we estimate an instrument for technology imports, we have to define what makes a commodity a technology product. For this exercise, we closely follow ECLAC (2002) and include, among others, chemical products with high technology contents, machinery, power engines, and instruments (Table 1). All these products have a relatively high R&D intensity in common. As for trade in technology products, we use Revision 1 of the Standard International Trade Classification (SITC), since we are employing annual data starting from 1965.[5] Not surprisingly, both production and exports of technology products are concentrated in a small number of countries. In fact, a group of 21 OECD economies account for more than 90 per cent of worldwide R&D expenditures in the period 1980 to 1995 and its manufacturing sectors are the main recipients of these investments (OECD, 2001).[6] To simplify the computation task, we extract times series of technology exports from these countries to the rest of the world by country on an annual basis.

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[4] Rodrik (1995) argues that trade policy is used in low productivity countries because it is an easy way to collect taxes.

[5] We would not be able to obtain trade data for the 1960s and 1970s if we use more recent revisions of the SITC.

[6] See Appendix A for the country list.

Table 1: Definition of Technology Goods

Product category	STIC No. (Rev. 1)
Medicine and various chemical products	541, 553
Machinery and power engines, excl. internal combustion engines	7111-7118
Specialised machinery, excl. paper and food machinery processing	722, 7231, 7249, 726, 729, 734
Instruments and various manufactures	861, 862, 864
Other technology products	9510

Source: Own definition based on ECLAC (2002).

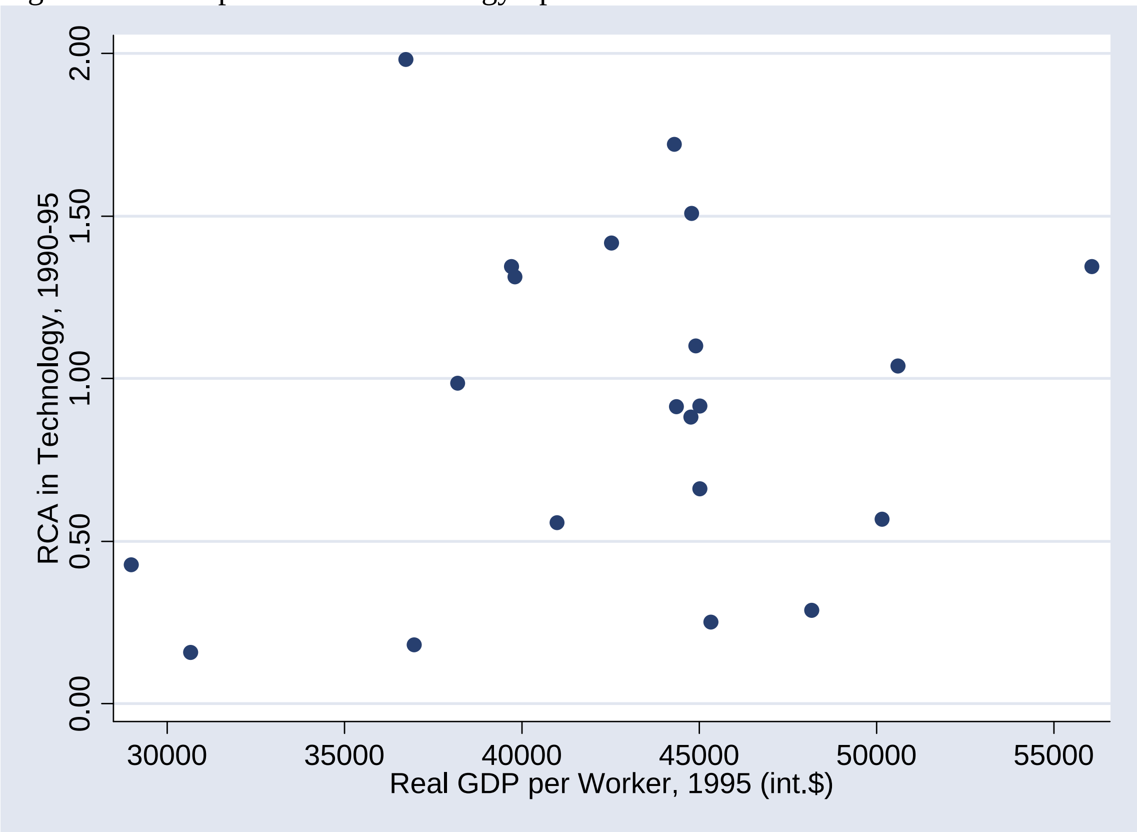
For the 21 OECD countries, we compute an index for the Revealed Comparative Advantage (RCA) in total technology trade[7]. A first look at simple scatter charts shows that the correlation between the RCA index and GDP per worker is relatively low and the correlation between the RCA index and R&D expenditure is relatively high (Figures 1 and 2). This outcome implies that a comparative advantage in R&D goods (as measured by RCA index) is a better predictor of technology specialisation than income and that the definition of technology goods we adopt is closely related with the R&D content of those goods.

[7] The RCA index is computed using the following expression:

$$RCA_{ij} = \frac{X_{ij} \big/ \sum_j X_{ij}}{\sum_i X_{ij} \big/ \sum_i \sum_j X_{ij}}$$

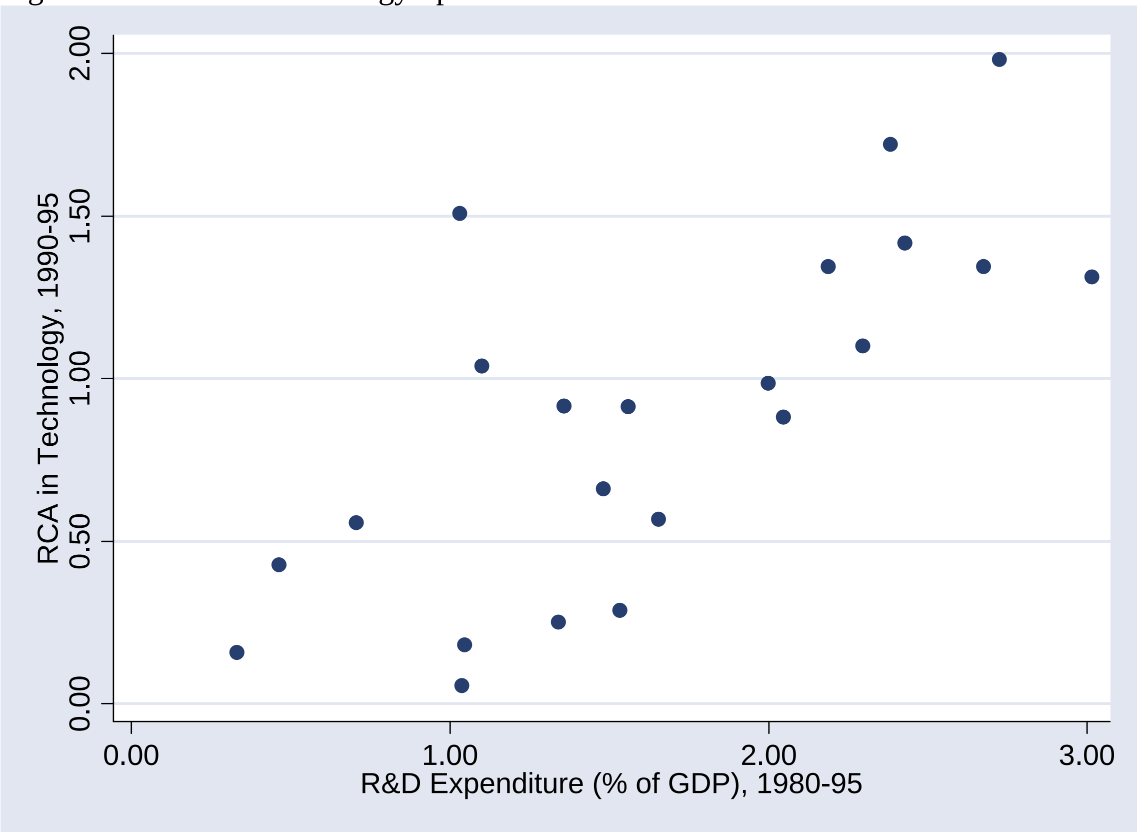
, where X_{ij} are technology exports (in US current dollars) in country *j* at a given moment. A value of 1.2 shows that country *j*'s technology exports relative to its total exports are 20 percent higher than the share of world technology exports relative to total world exports. Similarly, an RCA index of less than one can be interpreted as a technological disadvantage.

Figure 1: Development and Technology Specialisation



Note: In contrast to real GDP per worker figures, which are based on 1995 figures, we are using average RCA figures for the period 1990 to 1995, as many countries do not provide data on an annual basis. In addition, by compiling averages we reduce the effects of exchange rates fluctuations.

Figure 2: R&D and Technology Specialisation



Notes: See below Figure 1. Again, the time periods for both axes do not match. Changes in the export pattern (RCA index for 1990-95) are thought to take place slowly, since production patterns respond to R&D expenditures only during a longer period (1980-95).

Following this, we construct a new instrument for technology imports, which is required for the instrumental variable approach. For this exercise, we closely follow Frankel and Romer (1999), who compute values of trade flows predicted by the exogenous variables in a gravity model. This approach has the main advantage that geographical components of trade flows, such as the distance between trading partners, are identified and used (as an instrument) to examine the linkage between trade and income levels.

In general, gravity models in empirical studies are based on the simple idea that bilateral trade between country *i* and country *j* is a function of their physical distance and respective sizes. Economies of scale and complementarities play the key role in the theoretical foundations of this model. Trade between two economies which share a common border is more likely than trade between two economies separated by an ocean or a long distance ceteris paribus. Additionally, a small economy tends to trade more in relative terms than a large country.

A bilateral trade equation for technology products, derived from the gravity model, may have several specifications. Above all, a country's technology imports are negatively related to its distance to the technological leaders and positively to its respective size. We depart from a simple linear specification and estimate in logarithms, including various measures of size and proximity. Accordingly, our model intends to explain high-technology imports from OECD countries by all countries and reads as follows:[8]

$$\begin{aligned}\log m_{ijt} &= a_0 + a_1 \log D_{ij} + a_2 \log A_i + a_3 \log A_j + a_4 \log P_{it} + a_5 \log P_{jt} \\ &+ a_6 L_i + a_7 L_j + a_8 Cont + a_9 Cont \log D_{ij} + a_{10} Cont \log A_i + a_{11} Cont \log A_j + \\ &a_{12} Cont \log P_{it} + a_{13} Cont \log P_{ij} + a_{14} Cont\ L_i + a_{15} Cont\ L_j + e_{ijt}\end{aligned} \quad (1)$$

where m_{ijt} represents technology imports by country *i* from (OECD) country *j* divided by the GDP of the importing country at time *t*, *D* stands for the distance between countries *i* and *j*, *A* for (land) area, and *P* for population size. *L* is a dummy variable taking the value one when the country *i* or *j* has access to an ocean and zero otherwise. *Cont* represents another dummy to account for the fact that some countries share a common border (value equal to one) or not (zero). Importantly, all these explanatory variables are based on the geography of a country, that is, we estimate the influence of geography on imports of technology commodities originated from OECD economies. In addition, we include interactions between contiguity and distance, area, and population to explore the fact that countries with a common border trade more with each other.[9] Included in the analysis are all countries that reported trade data to the United Nations for the estimation period from 1965 to 1995 and for which data for all other variables are obtainable.[10] That leaves us with a sample of 108 countries.

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[8] The sample of importing countries includes the 21 OECD countries.
[9] Three per cent of all observations in our sample represent trade between countries that share a common border. However, when we consider trade between OECD economies, this portion rises to 94 per cent. In this respect, we follow Frankel and Romer (1999) with the aim of increasing the fit of our model.
[10] Data sources for all variables are provided in Appendix B.

Equation (1) is estimated using annual data from 1965 to 1995 and ordinary least squares (OLS) with standard errors that are robust to clustering, since country pairs are likely to be dependent across years. Additionally, we use time dummies given the possibility of aggregate shocks, that is, transport cost reductions. The results are shown in Table 2. The model explains 46 per cent of variations in bilateral technology imports from R&D performing countries to the rest of the world with a total of 54,395 observations. Column 1 shows the coefficients and column 2 the interaction terms of each variable to contiguity.

Table 2: Bilateral Technology Imports

	Log of Technology Imports	
	Coefficients (1)	Interaction Terms to Contiguity (2)
Constant	-16.00***	13.49***
	(-24.1)	(4.59)
Log of Distance	-0.76***	-0.42
	(-18.21)	(-1.44)
Log of Importer Area	-0.13***	0.21*
	(-5.38)	(1.8)
Log of Exporter Area	-0.36***	0.36***
	(-13.46)	(2.93)
Log of Importer Population	0.02	-0.59***
	(0.8)	(-5.06)
Log of Exporter Population	1.40***	-0.45***
	(46.79)	(-3.99)
Landlocked (Importer)	-0.47***	0.08
	(-4.92)	(0.24)
Landlocked (Exporter)	0.73***	-0.02
	(5.72)	(-0.06)
Observations	54395	
Adjusted R^2	0.46	

Notes: Robust *t*-statistics in parentheses; due to space constraints, time dummies are not reported; significance at the ten, five, and one per cent levels are denoted by *, **, ***, respectively.

The results are broadly as expected, that is, they have the expected sign and are highly significant at the one or five per cent level. Distance is the most influential variable with a coefficient below one. Area of the importer country is negatively related to technology imports, confirming the presumption that small countries tend to trade more with the rest of the world. The same can be said about the area of the exporter economy, i.e., the larger the area of the technology exporter the less are the technology imports from that exporter. Countries with a large population in absolute terms tend to acquire more technology through imports, yet the elasticity is very low and not significant. On the other hand, the technology exporter's population is also positively associated with imports, and the coefficient is highly significant. Landlocked economies tend to import 47 per cent less technology. Moreover, technology imports increase if the exporter economy is landlocked.

The results for the interactions with contiguity suggest that trade between countries sharing a common border is 4 per cent larger than trade with the remaining countries. The interactions of contiguity with respect to importer's and exporter's area are positive and significant. Having a larger population in the importer and in the exporter economies reduces technology imports when countries share a common border.

These results are generally in line with the literature. However, some exceptions appear. For instance, size measures that are fixed (surface area) are typically negatively associated with trade since larger economies are relatively more self-sufficient, but when there are common border interactions, the elasticity of importer area becomes positive (0.08 rather than -0.13). On the other hand, size measures that proxy scale effects, such as population, usually reflect both positive signs. Once we take into consideration the border effect interacted, the estimated elasticity of importer population turns out negative (-0.57) rather than positive (0.02). This means that the larger the market size of importing economy the more a country imports technology, given the common border effects. Finally, all time dummies are significant, positive and increasing in time. This is likely to be due to the observed reduction in transport costs and tariffs and other trade barriers over time and due to a time trend.[11]

Following our estimation strategy, once the bilateral technology import model has been estimated, a simple aggregation allows us to obtain the value of the overall technology

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[11] In order to evaluate the explanatory power of reductions in trade barriers we have computed the R^2 of the model without time dummies (0.449). Comparing this coefficient with the one presented in Table 2, this suggest that only a small fraction of technology imports variation is explained by the time dummies.

imported explained by a pure model of geography. We define $\log \hat{m}_{ijt}$ as the vector of predictions of equation (1):

$$\log \hat{m}_{ijt} = \hat{\beta}' X_{ijt} \tag{2}$$

where $\hat{\beta}$ is the coefficients vector estimated in the model (a_0, a_1, ..., a_{15}) and X_{ijt} is the vector of variables considered. Hence, the appropriate instrument for technology imports $\hat{M}_{ijt}$ can be computed as:

$$\hat{M}_{it} = \sum_{j=1}^{21} e^{\hat{\beta}' X_{ijt}} \tag{3}$$

3. EMPIRICAL SPECIFICATION

After the computation of the instrument for technology imports, we next introduce the specification of the econometric model to assess the determinants of per-capita income levels. In line with previous studies, we use a simple framework in which the log of GDP per capita in country i (Y_i) is a function of institutions (I_i), overall trade as a share of GDP in logs (T_i), imports of R&D intensive goods as a share of GDP in logs (M_i), the distance from the equator (DE_i), and an error term (e_i):[12]

$$\log Y_i = \alpha_0 + \alpha_1 I_i + \alpha_2 \log T_i + \alpha_3 \log M_i + \alpha_4 DE_i + e_i \tag{4}$$

By applying this model specification, based on data for the year 1995, we capture the three "deep" determinants of long-term development, which have been singled out in the literature before, plus imports of technology goods from the main R&D performing

[12] In contrast to the previous pooled time-series model, we now use a cross-sectional analysis that has been the preferred model specification in the literature. Moreover, we intend to explain per-capita income levels rather than short- to mid-term growth rates.

countries. This breakdown of income may appear simple a priori, because it omits other potential determinants of income and pushes them into the error term. Yet if the geographic and historical approach to the instruments is correct, there is no reason for additional exogenous determinants of income to be correlated with the instrument. Moreover, the inclusion of other variables in the estimation would not account for the overall effect of the deep determinants on income, leaving out any effects operating through its impact on these variables.

While the last three right-hand side variables in equation (4) are relatively easy to quantify, there are many ways to proxy institutional quality. For example, Rodrik et al. (2004) use the rule of law indicator provided by Kaufmann et al. (2002), Acemoglu et al. (2001) rely on expropriation risk, and Hall and Jones (1999) employ a bundle of government anti-diversion policies based on indicators from the International Country Risk Guide. To ensure that our results are comparable with those reported by Rodrik et al. (2004), we also use the rule of law indicator for institutional quality. This measure is originally constructed from indicators that reflect "the extent to which agents have confidence in and abide by the rules of society. These include perceptions of the incidence of both violent and non-violent crime, the effectiveness and predictability of the judiciary, and the enforceability of contracts" (Kaufmann et al., 2002: page 8). Both overall trade and technology imports are measured as an average of the volume of trade and imports (divided by GDP), respectively, during the period from 1965 to 1995.

Needless to say, apart from the distance from the equator, which is quantified as absolute value of latitude of the capital city,[13] all explanatory variables are endogenous. Thus, we will first estimate equation (4) using ordinary least squares (OLS) and then employ a two-stage least squares (2SLS) approach to capture the effect of variations in geography and history (exogenous) in the three endogenous variables. Our approach involves using Hall and Jones (1999) instruments for institutions, that is, the fraction of population speaking English or another major European language and a geographical variable (distance from equator), since employing alternative instruments, such as the

[13] To examine the robustness of the results, we later on add several other measures of geography.

settler mortality rates as in Acemoglu et al. (2001) would severely reduce the sample size. For overall trade, we rely on the Frankel and Romer (1999) instrument, while we use our own instrument for technology imports as described in the previous section.

While our sample of 108 countries is smaller than the largest sample of Rodrik et al. (2004), which consists of 137 countries, it is nevertheless larger than their preferred sample of 79 countries. Descriptive statistics for the variables used in the analysis are shown in Table 3. GDP per capita is measured at international constant 1996 dollars for the year 1995. This measure of output is more accurate to compare standards of living across different countries because it corrects for exchange rate fluctuations and price differences. The natural logarithm of this measure ranges from 5.77 to 10.25 in our country sample. The rule of law indicator is standardised taking values between -2.09 and 1.91 in our sample, with higher figures indicating a higher institutional quality. The most open economy during the period was Singapore with a trade/GDP ratio of 3.24, while the least open was India with a ratio of 0.14. Imports of R&D intensive products represent on average a rather small share of GDP, ranging from 0.26 to 6.82 per cent of domestic product. The United States is the country with the lowest share of technology imports in GDP (0.26 per cent), while Singapore has the highest (relative) intake of these products (6.82 per cent).

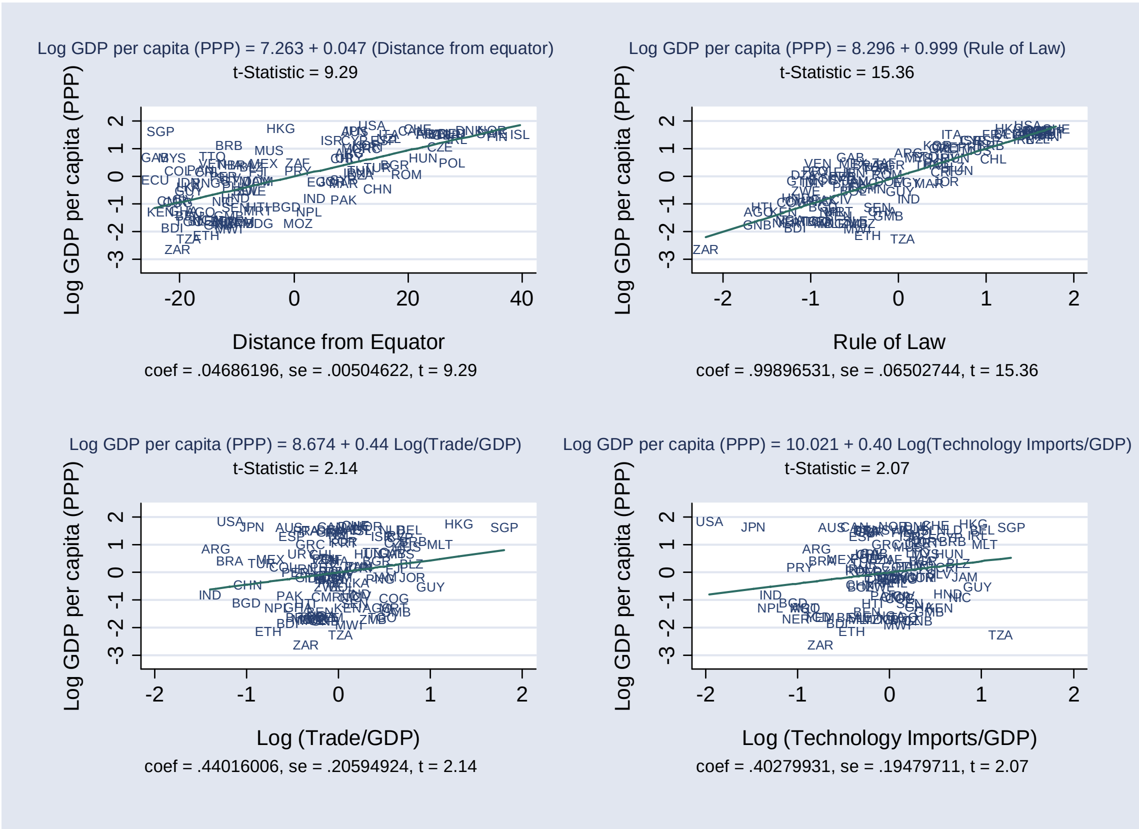
Table 3: Descriptive Statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Log GDP per capita (PPP)	8.41	1.18	5.77	10.25
Rule of Law	0.11	0.98	-2.09	1.91
Distance from equator	24.41	16.92	0.00	64.00
Log Trade	-0.61	0.55	-1.97	1.18
Log Technology Imports	-4.01	0.58	-5.97	-2.68
Log Constructed Trade	2.80	0.74	0.83	4.59
Log Constructed Technology Imports	-4.81	0.69	-6.00	-2.73
Fraction of population speaking English	0.09	0.26	0.00	1.00
Fraction of population speaking English or another major European language	0.29	0.41	0.00	1.00

Note: All figures relate to the sample of 108 countries.

Simple correlations of each four variables with GDP per capita, shown in Figure 3, reveal a positive and significant relationship. Of course, this does not prove causality, since these linkages may be the result of reverse causality, omitted variable bias or measurement error. They merely provide a first impression on how close the respective linkages with GDP per capita might be.

Figure 3: Partial Association between Income and its Determinants



Note: Coefficients and *t*-statistics based on a linear regression fit between income, a constant and the variable.

4. EMPIRICAL RESULTS

We start the presentation of the empirical findings with an overview of the first-stage regression results, which provide useful information about the overall relevance of our instruments (Table 4). For the rule of law, overall trade and technology imports, the overall fit of the model is relatively good, with a R^2 of 0.63, 0.61 and 0.52, respectively. We confirm previous findings about the positive relationship between distance from equator, language fractions and the quality of institutions. We could not establish any clear link between imports of technology and institutional quality. We also find that an exogenous increase of technology imports does not increase directly trade openness, but an increase in trade positively affects technology imports. It is well-known in instrumental variables regression that when instruments are weak, sampling distribution of the 2SLS estimator is not well approximated by its large-n normal approximation and classical methods of the inference are unreliable. To discard this possibility, we compute the first-stage *F-statistic* to test the hypothesis that the instruments do not enter in the first-stage regression. Weak instruments imply small first-stage *F-statistics.* We adopt the threshold value of ten recommended by Staiger and Stock (1997) for the *F-statistics* and we discard weak instruments since the *F-statistics* are far above (50.32, 35.48 and 25.81 for institutions, overall trade and technology imports, respectively).

Table 4: First-Stage Regressions

	Rule of Law (1)	Trade Openness (2)	Technology Imports (3)
Distance from Equator	0.035***	-0.007**	-0.013***
	(6.08)	(-2.39)	(-3.14)
Fraction of Population speaking English	0.697***	0.447***	0.105
	(2.79)	(3.92)	(0.49)
Fraction of Population speaking English or another European Language	0.396***	-0.172**	0.119
	(2.64)	(-2.3)	(1.41)
Log Constructed Technology Imports	0.159	0.138	0.449***
	(1.13)	(1.6)	(3.83)
Log Constructed Trade	0.154*	0.488***	0.299***
	(1.9)	(8.21)	(3.89)
Constant	-0.591	-1.133*	-2.410***
	(-0.64)	(-1.91)	(-2.95)
Observations	108	108	108
R^2	0.63	0.61	0.52
F-test	50.32	35.48	25.81
p-value	0.00	0.00	0.00

Notes: Robust *t*-statistics in parentheses; significance at the ten, five, and one per cent levels are denoted by *, **, ***, respectively; *F*-test is the test of joint significance of all the regressors.

When several instruments are used at the same time for three endogenous variables, it is difficult to assess whether the instruments are appropriate. To address this concern, we compute the partial correlations among the endogenous variables and the predicted values from the first-stage regressions. For actual values of rule of law, trade and technology imports, the correlations with the predicted values are very high (Table 5). We also find that our instrument's predictions are moderately correlated, except with the predicted value of technology imports and predicted trade (correlation equal to 0.91). We will assess the potential consequence of this outcome below.

Table 5: Correlations among Explanatory Variables

		Distance from Equator	Rule of Law	Log Trade	Log Technology Imports	Predicted Rule of Law	Predicted Log Trade	Predicted Log Technology Imports
	Distance from Equator	1.00						
	Rule of Law	0.71	1.00					
	Log Trade	-0.06	0.24	1.00				
	Log Technology Imports	-0.01	0.25	0.73	1.00			
Predicted	Rule of Law	0.90	0.79	0.13	0.20	1.00		
Predicted	Log Trade	-0.07	0.14	0.78	0.66	0.17	1.00	
Predicted	Log Technology Imports	-0.01	0.21	0.72	0.72	0.27	0.91	1.00

Following this, we present the outcome of the estimation for equation (4). The first two columns in Table 6 reflect the influence of trade on income once we control for distance from the equator (geography). Similar to previous findings, openness to trade does not exert a significant influence on income in the two-stage approach. We then extend the model and include institutions in the next two columns. These are the basic specifications of Rodrik et al. (2004). The coefficients of institutions and trade openness are very similar in size to those obtained by Rodrik and associates in their preferred sample of 80 countries. For our sample, we can confirm that institutional quality is by far the most important variable explaining cross-country differences in per-capita income levels. What is more, trade does not have a positive but rather a negative impact on income levels in the instrumental variable regressions. Yet this outcome is not robust to all specifications. To test for the orthogonality of the error term and the instruments, we report the test for overidentifying restrictions of the model (*J*-test). These restrictions are rejected, meaning that the instruments are not exogenous (as in the large sample in Rodrik et al., 2004).

Table 6: Determinants of Income, OLS and 2SLS

	Dependent variable: Log GDP per Capita					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Distance from Equator	0.05***	0.05***	0.01**	-0.01	0.01**	-0.01
	(11.33)	(11.07)	(2.27)	(1.42)	(2.32)	(-0.75)
Rule of Law			0.83***	1.43***	0.83***	1.24***
			(9.6)	(7.03)	(10.16)	(5.73)
Log Trade	0.52***	0.24	0.1	-0.35*	0.12	-1.09**
	(2.73)	(1.08)	(0.78)	(-1.9)	(0.53)	(-2.45)
Log Technology Imports					-0.03	0.94*
					(-0.14)	(1.88)
Constant	7.56***	7.40***	8.06***	8.35***	7.96***	11.54***
	(37.46)	(33.81)	(53.34)	(47.15)	(10.02)	(6.66)
Shea partial R^2 (first-stage)						
Rule of Law				0.20		0.18
Trade		0.57		0.52		0.23
Technology Imports						0.16
Observations	108	108	108	108	108	108
R-squared	0.51		0.7		0.71	
OID: *J*-test (*p*-value)				0.02		0.33

Notes: Robust *t*- and *z*-statistics in parentheses; significance at the ten, five, and one per cent levels are denoted by *, **, ***, respectively.

The fifth and sixth columns extend the model to include technology imports and to capture the particular effect that arises from the interaction with the more advanced economies through trade. In the instrumental variable regressions, institutions are still positive and significant but the coefficient is slightly smaller than in the previous specification. While trade openness also has a significant negative impact on income, the coefficient for technology imports is positive and significant at the ten per cent level. The test for the overidentifying restrictions shows that we cannot reject the hypothesis that our instruments are exogenous. This outcome supports our choice of the set-up of the instrumental variable approach to identify the separate effects of trade and technology imports on income, apart from the rest of the influences. Above all, the results imply that geography and history shape the world income distribution in the base year through institutional quality and technology imports.[14]

The first-stage regressions, reported in Table 4, confirm that our set of instruments is strongly related to the endogenous determinants of income. However, it is difficult to evaluate the instruments' relevance when we use them at the same time for all three endogenous variables. We have shown above that predicted technology imports and predicted overall trade are strongly correlated and this may complicate the identification in the second stage of the separate effect of both variables on income. We assess this issue by reporting Shea's (1997) partial R^2 for the respective instrumented endogenous variables (Table 6). The test suggests that the instruments are relevant in Shea's sense, as all figures for the partial R^2 are above 0.10 and the *F*-tests, upon excluding the instruments, have *p*-values of below 0.01.

To check the robustness of this outcome, we perform various additional tests (Table 7). First of all, as we have discovered distance from the equator may not affect income levels directly, though there is an indirect effect that acts through the quality of institutions. Thus, we exclude this variable in a first robustness check (column 1). On the other hand, Frankel and Romer (1999) argue that smaller countries tend to trade more than large countries but that size may have other direct effects, such as the ones predicted by the new growth theory. To control for this fact, we include two measures of size, i.e., population and (land) area (columns 2 and 3). Additionally, we check the possibility that our particular measure of geography is driving the results. It can be argued that countries in a given geographic location perform systematically better than others and that these differences may explain the results. Rodriguez and Rodrik (2000) and Irwin and Terviö (2002) suggest that previous studies evaluating the effect of trade

[14] Our findings suggest that once geography, institutional quality and imports of R&D intensive goods from OECD are considered, overall trade has a negative impact on income levels in a cross-country setting. Several theories establish that openness to trade and specialization might hurt income levels in several ways (see Grossman and Helpman (1995) for a compelling survey). We are unable to provide a specific explanation for this outcome, given that our exercise is not a proper test of any of these theories. However, Alesina et al. (2005) have taken into consideration the role of trade and size in economic growth. Under their review of the literature trade openness has favourable effects on growth and income

on income such as Frankel and Romer (1999) are not robust to the inclusion of latitude as an explanatory variable. To address this concern, we include latitude instead of distance from equator[15] and reestimate by 2SLS (column 4). Moreover, McArthur and Sachs (2001) suggest that other geographic variables, such as fraction of population living in tropical areas or the portion of land in tropical areas affect income through diseases and morbidity. We add those measures as control variables, too (columns 5 and 6). Importantly, all robustness checks present a similar pattern. Independent of the model specification, technology imports always have a positive and significant impact on per-capita income levels.

Table 7: Robustness Checks, 2SLS

	Dependent variable: Log GDP per capita					
	(1)	(2)	(3)	(4)	(5)	(6)
Rule of Law	1.111***	1.094***	1.104***	1.114***	0.964***	1.026***
	(10.04)	(8.42)	(10.25)	(8.93)	(9.95)	(6.00)
Log Trade	-1.101**	-1.889***	-1.317***	-1.051**	-0.858*	-1.104**
	(-2.51)	(-3.21)	(-2.96)	(-2.48)	(-1.91)	(-2.55)
Log Technology Imports	1.023**	1.399***	0.920*	0.943**	0.801*	1.058**
	(2.15)	(2.8)	(1.78)	(2.11)	(1.73)	(2.18)
Log Population		-0.17				
		(-1.47)				
Log Area			-0.079			
			(-0.92)			
Latitude				0.000		
				(0.04)		
Population in Tropics					-0.520**	
					(-2.12)	
Land in Tropics						-0.172
						(-0.79)
Constant	11.714***	15.512***	12.134***	11.424***	11.148***	11.959***
	(6.99)	(6.2)	(7.9)	(7.31)	(7.06)	(6.75)
Observations	108	108	108	108	108	108

Notes: Robust *z*-statistics in parentheses; significance at the ten, five, and one per cent levels are denoted by *, **, ***, respectively.

Another concern arises with the choice of our measure of trade openness. So far, we have used total trade as a measure for openness, that is, imports and exports. Principally, we have followed Bernard and Jensen (1999) and Funk (2001), who argue

levels, but the effects of size become less important as an economy becomes more open. Given the endogeneity of population in this type of analysis we cannot discard this possibility.

that there can be technology spillovers not only through imports but through exports too, as firms increase their competitiveness. Yet it can be argued that only imports should be used, since the empirical evidence on technology spillovers is much stronger for imports and exports are only good to pay for imports (Rodrik, 1999).

Still, the results on the role of high-tech imports presented in this section could capture either the effects of total imports in general (or total imports from OECD countries included) rather than high tech imports, as they are closely associated with each other. If that is the case, the interpretation of the results would be different. Accordingly, we perform two further regressions of the last specification (column 6) in Table 6. The first uses total imports rather than total trade. The coefficient (standard error) of the (log of) imports is -1.34 (0.497), while the coefficient (standard error) of the (log of) technology import is 1.03 (0.518). Thus, the coefficient for (and significance level of) high-technology trade is robust to different trade measures.

As the second additional regression, we employ a measure of overall trade interactions with the OECD but not with the rest of the world. The coefficients are estimated with less precision but they are very similar. The coefficients (standard errors) of the (log of) trade with the OECD and the (log of) technology imports are -1.02 (0.581) and 0.90 (0.636) respectively. This means that, even when controlling for trade with the OECD, high-technology trade is an important source for explaining variations in income levels[16].

Finally, we have considered changes in the sample, for instance, by excluding the countries that do not appear in the sample used by Acemoglu et al. (2001) or by excluding technology exporters. Importantly, the basic outcome does not change much.[17] To sum up, our results re-establish the role of trade in explaining the variance

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[15] Distance from equator differs from latitude because it is calculated as the absolute value of latitude in a scale that ranges from 0 to 60.

[16] We have re-run specifications in Table 7 by employing as a measure of openness the share of trade subtracting technology imports. The results indicate that trade is negatively associated with income and that technology imports increase income levels consistently.

[17] Results are available from the second author upon request.

of income levels across countries, though this is closely linked to a particular kind of trade, that is, technology imports.

5. CHANNELS THROUGH WHICH TECHNOLOGY IMPORTS AFFECT PRODUCTIVITY

In a further empirical analysis, we depart from Hall and Jones (1999) development accounting exercise to detect the channels through which technology imports affect productivity in the cross section of countries. The log of GDP per worker may be broken down into the three components of total factor productivity, human capital and physical capital:

$$\log y_{\mathrm{i}} = \frac{\alpha}{1-\alpha}\log\left(\frac{K_i}{GDP_i}\right) + \log h_i + \log A_i \qquad (5)$$

where $\alpha = 1/3$, K is the stock of physical capital, h is a measure of human capital per worker based on schooling years, and A is the total factor productivity (TFP) term.

The exercise comprises the regressing of each component of output per worker on the distance from equator, rule of law, total trade, and technology imports following the 2SLS estimation procedure. In our analysis, we employ the same dataset that Hall and Jones (1999) use for their computations.[18] Unfortunately, merging both datasheets implies that four observations are lost, which reduces the sample to 104 countries. On a priori grounds one expects to find a strong correlation between technology imports and physical capital, because importing technology is a way of accumulating new capital goods, as stressed by the traditional growth theory. Additionally, high-tech trade may act as a substitute for human capital with countries importing human capital embodied in high-tech goods (Ramcharan, 2004). Finally, we can expect to find a high correlation

[18] The dataset is available at Charles Jones' web page: http://elsa.berkeley.edu/~chad/datasets.html.

between technology imports and the index of TFP, as emphasised by the technology diffusion literature.

Table 8 shows the estimation results of the level accounting exercise. It is worth noting that the model presents similar coefficients for output per worker as for per-capita income. Institutions matter for the three components, but both technology imports and openness affect GDP per worker only through total factor productivity. Hence, while importing technology raises total factor productivity, increasing overall trade openness may hurt it.

Table 8: Channels of Influence

	GDP per Worker	Physical Capital	Human Capital	Total Factor Productivity
	(1)	(2)	(3)	(4)
Distance from Equator	-0.011	-0.004	-0.004	-0.003
	(-1.06)	(-0.9)	(-1.57)	(-0.23)
Rule of Law	1.174***	0.286***	0.362***	0.526*
	(4.69)	(2.72)	(6.77)	(1.92)
Log Trade	-1.263**	-0.172	-0.104	-0.986**
	(-2.49)	(-1.14)	(-0.88)	(-2.32)
Log Technology Imports	1.130**	0.079	-0.04	1.091**
	(2.09)	(0.47)	(-0.33)	(2.32)
Constant	12.716***	0.528	0.444	11.744***
	(6.84)	(0.94)	(1.04)	(7.52)
Observations	104	104	104	104
R^2	0.37	0.08	0.5	0.04

Notes: Robust *t* values in parentheses; significance at the ten, five, and one per cent levels are denoted by *, **, ***, respectively.

6. CONCLUDING REMARKS

Countries' income levels differ in the long run mainly because the ability to use resources differs. Institutions, geography and economic integration are the three plausible explanations of the deep determinants in economic success. Prior studies have detected that the effect of institutional quality predominates over the effect of trade in explaining these differences. However, recent theories and evidence suggest that trade in capital goods (and not overall trade) is a conduit of R&D spillovers, and that importer countries obtain significant benefits in terms of mid-term productivity growth.

We reconcile these two strands of the literature by estimating separately the effects of trade on income levels from the effects of technology imports and other deep determinants. We construct an instrument for technology imports based on geography, exploiting the idea that bilateral total trade and technology trade patterns are likely to be affected in a similar way by geography. However, since institutions affect the ability of countries to use new technologies, technology imports is affected in a different way than overall trade. To the extent that such trade is determined by geography and history, we obtain unbiased and consistent estimates of the effects of technology imports on income, output per worker and total factor productivity levels.

We confirm previous evidence that institutions influence development and that this effect dominates overall trade openness. Importantly, we present evidence that imports of R&D intensive goods contribute to economic development once the effect of institutional quality and economic integration are controlled for. In the long-run technology diffusion through trade increases income levels via total factor productivity, in turn reducing the income gaps among countries. At a country level, these results are in line with those reported by Blalock and Veloso (2005), who use firm-level data for Indonesian manufacturing firms and find that (technology) imports are a driver of technology transfer. To sum up, to raise income levels the total trading volume is not as important as the trade composition, in particular when it comes to technology imports.

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APPENDIX A: COUNTRY SAMPLE

Algeria, Angola, Argentina, *Australia*, *Austria*, Bangladesh, Barbados, *Belgium-Luxembourg*, Belize, Benin, Bolivia, Brazil, Bulgaria, Burkina Faso, Burundi, Cameroon, *Canada*, Chad, Chile, China, Colombia, Congo, Costa Rica, Cyprus, Czechoslovakia, *Denmark*, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Fiji, *Finland*, *France*, Gabon, Gambia, *Germany*, Ghana, *Greece*, Guatemala, Guinea-Bissau, Guyana, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, *Ireland*, Israel, *Italy*, Ivory Coast, Jamaica, *Japan*, Jordan, Kenya, Korea (Republic), Madagascar, Malawi, Malaysia, Mali, Malta, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Nepal, *Netherlands*, *New Zealand*, Nicaragua, Niger, Nigeria, *Norway*, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, *Portugal*, Romania, Senegal, Sierra Leone, Singapore, South Africa, *Spain*, Sri Lanka, *Sweden*, *Switzerland*, Syria, Tanzania, Thailand, Togo, Trinidad & Tobago, Tunisia, Turkey, *United Kingdom*, *United States*, Uruguay, Venezuela, Yemen, Zaire, Zambia, Zimbabwe

Note: Countries in italics are the 21 OECD countries that are the main exporters of technology goods.

APPENDIX B: DEFINITION OF VARIABLES AND DATA SOURCES

Variable	Definition	Source
GDP (Y)	Gross Domestic Product per capita, measured at international constant 1996 US dollars	Penn World Table Mark 6.1 updated version of Summers and Heston (1991)
Technology imports (M)	Technology imports divided by GDP	UNCTAD (2005) and World Bank (2005)
Constructed Technology imports	Our own instrument for technology imports divided by GDP	
Trade (T)	Total imports and exports of goods divided by GDP	UNCTAD (2005) and World Bank (2005)
Constructed Trade	Frankel and Romer (1999) instrument for total trade divided by GDP	Hall and Jones (1999)
Distance (D)	Distance between countries, measured as great circle between two capital cities	Haveman (2005)
Distance from equator (DE)	Distance from the equator, measured as absolute value of latitude of capital city	Hall and Jones (1999)
Rule of Law (I)	Indicator measuring the extent and enforcement of the rule of laws, standardised values, range from -2.5 to +2.5	Kaufmann et al. (2002)
	Fraction of the population speaking English, per cent	Hall and Jones (1999)
	Fraction of the population speaking a major European Language, per cent	Hall and Jones (1999)
Cont	Dummy for common border, 0 and 1	Haveman (2005)
Landlock (L)	Dummy for countries with access to the ocean, 0 and 1	Easterly and Sewadeh (2001)
Latitude	Latitude of the capital city	Easterly and Sewadeh (2001)
Area (A)	Land area, measured in mill. sq. kilometre	World Bank (2005)
Population	Total population in million	World Bank (2005)
Population in Tropics	Fraction of the population living in tropical areas	Gallup, Sachs and Mellinger (1999)
Land in Tropics	Share of the land area in tropical area	Gallup, Sachs and Mellinger (1999)

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