Technology trade, productivity and growth

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Abstract

International trade is a major channel for technology diffusion. However regressing trade in R&D intensive goods to evaluate the effect of technology imports on productivity in a cross section of countries may be misleading because of simultaneity bias. I identify the effect of technology trade on productivity using geographical instruments for the trade variable as in Frankel and Romer (1999). I make several contributions. First, I provide evidence that OLS estimates are downward biased. Second, the effect is robust to the exclusion of outliers, the inclusion of latitude, and to different subsamples. Finally, I document the channels throughout technology imports affect productivity.

Keywords: Growth, Technology Diffusion, Instrumental Variables, R&D Spillovers, Capital Goods.

JEL Classification: C31, O11, O40.

Recently, endogenous growth models have shed a good deal of light on the dynamic gains of international trade[1]. Exchange between two countries enhances the diffusion of technological and organizational knowledge from the more advanced economies to the rest of the world, and hence, stimulate productivity.

There are several channels through which knowledge spillovers potentially take place. First, international trade allows countries to gain access to a broader variety of intermediates and capital goods. Second, contact through borders establish communication channels needed for learning new production processes, new designs, or new management techniques. Third, trade facilitates copying and adaptation foreign technologies to domestic uses. And forth, openness to trade improves the productivity in imitating and developing new technologies from abroad. Several technological spillovers take place throughout FDI and personal contacts. However, an evaluation of each of these channels is a difficult task and still more difficult to link technology diffusion to trade openness. Keller (2001) is an attempt to disentangle alternative ways such as foreign direct investment or trade as channels of technology diffusion in seven industrialized economies. Not surprisingly he find that trade is the most important channel of diffusion.

This paper is an exploration about the links of the causal relationship between trade and growth. I focus on the trade of R&D intensive goods as a way of technology flows through borders. In fact, innovation processes are concentrated in a handful of countries and these economies are the major capital good producers and exporters, as documented by Eaton and Kortum (2001). This suggests that developing economies import from R&D intensive economies technology that is embodied in those goods. A measure of disaggregated capital stock by R&D intensity unfortunately is not available, but imports of certain goods are a reasonable proxy for embodied technology investments in a developing country.

R&D investment is a key input in the production of new technologies. A group of twenty one OECD economies concentrate more than 90 per cent world R&D expenditures. Manufacturing sector is the main recipient of those investments. Several industries are more R&D intensives than others, then, I restrict the technological sector

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[1] See Rivera-Batiz and Romer (1991a, 1991b), Grossman and Helpman (1991), Barro and Sala-i-Martin (1995) and Aghion and Howitt (1998).

to those manufacturing sectors relatively R&D intensive in OECD economies[2]. To account for technology trade I used a taxonomy based on Standard International Trade Classification (SITC) revision 1 at 4-digit level and similar to that used in ECLAC (2002) from COMTRADE. I extract times series of technology exports from OECD economies to the rest of the world by country since 1965 at annual basis. Technology is the sum of the following R&D intensive sectors: medicines and several chemical products (SITC 541+553), machinery and power engines excluding internal combustion engines (SITC 7111-7118), specialized machinery excluding paper and food machinery processing (SITC 722+7231+7249+726+729+734), instruments and various manufactures (SITC 861+862+864) and others (SITC 9510).

Differences in technology specialization among OECD economies are enormous. Table 1 show the share of technology exports in each country between 1965 and 1995. For the OECD as a whole, technology exports represented 1 per cent of GDP in 1965, whereas in 1995 it represents 3 per cent. All the countries have experienced an increase in its relative specialization along the period considered. Ireland is the most dynamic case; however Belgium (including Luxembourg) has experienced a dramatic increase as well. There are several countries that export above the average along the period, such as Switzerland, Germany or Netherlands. In a lower position there are Denmark, France, Ireland, United Kingdom, Norway and Sweden. On the other hand, there is a group of countries exporting a lower fraction of its GDP in technology. This group is formed by Australia, Austria, Spain, Finland, Greece, Italy, Japan, New Zealand, Portugal and USA. Astonishingly, Japan and USA are high-income countries investing a large amount in R&D activities but having a low rate of technology exports. However, using the revealed comparative advantage index (RCA) results are quite different. In Figures 1 and 2 I see the low correlation between the RCA index and GDP per worker in OECD economies and the high correlation between the RCA index and the R&D expenditure. This means that R&D is a better predictor of technology specialization than income.

I depart from this fact to evaluate the effects of trade in "technology" on productivity and long term growth. This paper is a contribution to the literature of growth empirics in the way to deal with the problem of endogeneity in the productivity

[2] A complete characterization of R&D distribution among countries and sectors is in OECD (2001).

regression. Trying to estimate the effect of technology imports on productivity by OLS regressions may not reflect the effect of technology on productivity. The simultaneity bias arises because the correlation of technology imports and productivity could mean that countries with higher productivity import more technology rather the other way around. Frankel and Romer (1999) developed a method for calculate an instrumental variable to solve the endogeneity problem using geographic information about bilateral trade. However, Frankel and Romer's method cannot isolate the channel through trade (by exports or by imports) affect economic performance. In this paper I propose a specific treatment for imports endogeneity using geographic information about bilateral technology flows to get an instrument for overall technology imports.

This paper is also related to previous works about the role of capital goods imports on economic growth. Lee (1995) presents a model in which the use of more imported inputs increase the efficiency of capital accumulation spurring long term growth. He estimate using an instrumental variable (IV) for capital goods imports in a growth regression equation finding a significant positive relationship. However, the instrument he uses is a mix of geography (distance to trade partners and area) and policy variables (tariff rates). Whereas the former are exogenous the latter may not[3]. I differ from Lee (1995) in two aspects, first I don't use simply capital goods but a more complex definition, i.e. R&D intensive products, and second, I employ only geographic information on imports to instrument in the growth regression.

The paper is also clearly related to the empirical technology diffusion literature[4]. Whereas most of these papers estimate a productivity equation in (5 years) differences their findings about the relationship of imports on growth are far from being long term relationships. In addition there are not specific treatments for endogeneity. Using a different methodology Eaton and Kortum (2001) find that geographic barriers to trade in capital goods explain a high percentage of international differences in productivity. Also Caselli and Wilson (2003) exploit the investment composition effect (measured by imports of different capital goods) for explaining the cross-country variation in per capita income.

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[3] Rodrick (1995) argue that trade policy is used in low productivity countries because is an easy way to collect taxes.

[4] E.g. Coe and Helpman (1995), Coe, Helpman and Hoffmaister (1997), Keller (1998), Crespo, Martín and Velázquez (2002).

I start the next section of the paper describing the estimation strategy. In Section 2 I calculate the instrument variable and evaluate the quality of the instrument. In Section 3 I present the estimation results. And finally in Section 4 I summarize and evaluate the results.

1 Empirical strategy

New trade theories have found theoretical arguments for using gravity models in empirical studies. The simple idea is that bilateral trade from 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. Hence, trade between two economies separated by a land border is more likely than trade between two economies separated by an ocean or too many kilometers of distance *ceteris paribus*. Additionally, a small economy tends to trade more *vis a vis* with a large country than two large countries between them.

The basic gravity equation is the following:

$$(1)\ \tau_{ij} = \beta_0 D_{ij}^{\beta_1} S_i^{\beta_2} S_j^{\beta_3}$$

Where τ_{ij} is the sum of exports and imports between *i* and *j* to *i*'s GDP, D_{ij} is distance, S_i and S_j are *i* and *j*'s sizes respectively.

Equation (1) can be estimated including as much indicators of size and distance as available. The strategy I follow in estimation consist in obtain an instrumental variable from the gravity equation (1) been m_{ijt} the technology imports flowing in country *i* from country *j* in time *t* the dependent variable. All the right hand side variables are geographic variables, and hence exogenous in a growth regression. Once estimated equation (1) I aggregate to get all the technology imports originated in R&D performing countries ($M_{it} = \sum_j m_{ijt}$) country by country. The result is quite clear; I get the technology imports in a cross section of economies explained by a pure model of geography. This method discards the possibility of endogeneity and assures efficiency and consistency in a productivity equation.

Productivity is a result of interactions taking place inside and outside of a country. Traditional growth theory has introduced several ways of analyzing the growth determinants in a closed economy. New growth theorists have shed new lights on the external linkages emphasizing the international flow of knowledge through trade. Openness to trade may alter the specialization pattern in a world in which some countries have comparative advantage to produce ideas. Moreover, international knowledge spillovers increase productivity, i.e. importing machinery, and probably accelerate long term growth in the presence of scale effects, as suggested by Grossman and Helpman (1991) and Lee (1995).

In the simple framework I propose GDP per worker in country i (y_i) is a linear function of the share of imports of R&D intensive goods to GDP (M_i) that reflect the positive effect of investing a country's trade partner's new technologies and a set of exogenous variables (I_i) that capture the effect of other sources of technology adoption. In order to provide consistency to the geography approach I consider as (I_i) variables the log of population and the log of area as exogenous variables. Moreover, new growth theory suggests the possibility of scale effects operating through the production of new technologies. The error term reflects the rest of influences.

$$(2)\quad \log y_i = \alpha_0 + \alpha_1 I_i + \alpha_2 M_i + e_i$$

The main feature of the equation is that all the independent variables but imports are of geographic nature. The key insight of this approach is that a country's geographic attributes may act as instruments of technology imports. Since distance and size are highly correlated with trade, although are independent of productivity, can be used to identify the effect of technology imports on productivity. There are of course other relevant factors determining productivity, all of them are relegated to the error term since they are likely independent of the instrument. I will look further into that possibility.

2. The instrumental variable

2.1 DATA DESCRIPTION

Table 2 reflects technology imports share from 1965 to 1995. This is a long period for trade statistics and UN statistical information reveal some gaps for several countries. This is not a serious problem since I am interested in long term relationships; hence I take averages for the period in countries with no less than 10 annual observations and discard the rest of countries. The resulting sample includes 21 OECD economies and 69 developing countries non oil exporters. Economies are grouped according to geographic information exclusively. Data show East Asia and Pacific and Latin American economies the more technology importer regions. Conversely, the less technology importer regions are North America and South Asia. It is clear that the former is a producer and exporter of technology while the latter is not.

2.2 TECHNOLOGY IMPORTS FUNCTION

Bilateral trade equation derived from the gravity model (1) may have several specifications. I hope a country technology imports are negatively related to its distance to the technological leaders and positively to its respective size. I depart from a simple linear specification including various measures of size and proximity. The estimated equation is:

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\begin{aligned}
(3)\quad & \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 Long_i + a_9 Long_j + a_{10} Lati_i + a_{11} Lati_j + \\
& a_{12} Cont + a_{13} Cont \log D_{ij} + a_{14} Cont \log A_i + a_{15} Cont \log A_j + \\
& a_{16} Cont \log P_{it} + a_{17} Cont \log P_{jt} + a_{18} Cont\, L_i + a_{19} Cont\, L_j + e_{ijt}
\end{aligned}
$$

Where, in addition to the known variables, L is a dummy taking the value 1 when the country i or j have access to an ocean and take the value 0 otherwise; *Long* is the country longitude in absolute value, *Lati* is the latitude in absolute value, both reflect climate influences, *Cont* a dummy variable taking the value 1 when the importer and the exporter share a common border and take the value 0 otherwise. All the variables are of geography and I am going to test whether this simple model can explain technology imports originated in OECD economies. I include interactions between *Cont* and distance, area, population and L trying to measure the higher weight of trade among countries sharing a border.

Trade data comes from COMTRADE database. Importer countries are those that reported data to United Nations and R&D performer countries are those reflected in Table 2. Technology imports are divided by current GDP in US dollars, as provided by World Bank (2001). Distance is measured by great circle between two capital cities and jointly to contiguity has been provided by Haveman (2000). Data on area and population are from World Bank (2001) and landlocked dummy, latitude and longitude are from Easterly and Sewadeh (2001).

Equation (6) is estimated using a large amount of observations by ordinary least squares (OLS) with standard errors that are robust to clustering, since country pairs are likely to be dependent across years. Additionally I use time dummies given the possibility of aggregate shocks, i.e. transport cost reductions.

Table 3 show estimation results of equation (3). The model explains 54 per cent of variations in bilateral technology imports from R&D performing countries to the rest of the world. The first column shows the coefficients and the second the interaction terms of each variable to contiguity. Because of space restrictions I have omitted time dummies.

Results speak by themselves. The entire hypothesis appears to be confirmed and almost all the coefficients are significant at 1 per cent. Distance is the most influential variable with a coefficient close to 1. Area of the importer country is negatively related to technology imports, this fact confirm 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, the larger the area of the technology exporter the less are the technology imports. Populated economies in absolute terms tend to acquire less technology to worldwide exporters, yet the elasticity is very low and not significant. The same can be said about technology exporter's population, economies tend to import more technology from populated countries. Landlocked economies tend to import 41 per cent less technology; moreover technology imports increases if the exporter economy is landlocked. This means that natural barriers such as access to an ocean are not an obstacle for exporting in R&D performing countries as in developing economies. Variables measuring climate influences exert a different effect. Distance to Greenwich is negative for the importer and positive for the exporter. Latitude may reflect climate influences but also western influence, the larger the distance to Equator in the importer economy the less is the technology import share. This fact will motivate further exploration in the productivity and in the growth regressions.

The column measuring interactions to contiguity reflects that trade between countries sharing a common border is nine time larger than trade with the rest of countries. The interactions of contiguity with respect importer and exporter's area are positive but non significant. Population in the importer and in the exporter economies reduces technology imports when countries share a common border.

Time dummies are also interesting. All of them are significant, positive and increasing in time. This is consistent to the reduction of transport cost observed in the literature and to the fact that there is a time trend.

Following our estimation strategy, once a bilateral technology imports model have been estimated, a simple aggregation allow us to obtain the value of the overall technology imported explained by a pure model of geography. Let define $\log \hat{m}_{ijt}$ as the vector of predictions of the model (3):

$$(4)\ \log \hat{m}_{ijt} = \hat{\beta}' X_{ijt}$$

Where $\hat{\beta}$ is the coefficients vector estimated in the model (a_0, a_1, ..., a20) appearing in Table 3 and X_{ijt} is the vector of variables considered. Hence, the sum of the technology imports from the twenty one R&D performing economies will be:

$$(5)\ \hat{M}_{it} = \sum_{j=21} e^{\hat{\beta}' X_{ijt}}$$

Technology imports are a potential determinant of productivity and a source of growth in the long term when there is a sustained propensity to adopt foreign knowledge embodied in goods. The instrumental variable for M_i is an average over the period considered for each cross sectional unit ($\hat{M}_i$).

2.3 THE INSTRUMENT QUALITY

Figure 4 plot the relationship between the two variables, the technology imports share observed and the fitted measure estimated by the gravity model. The correlation between M_i and $\hat{M}_i$ is 0.58 and a regression of $\hat{M}_i$ on a constant and M_i yields a coefficient of 0.66 significant at 1 per cent level as shown in Table 4. Figure 4 also reveal two outliers, Netherlands and Belgium, which have a higher fitted share given its geographic attributes. When I remove those observations the coefficient of M_i on $\hat{M}_i$ rises to 0.87.

Is not an intriguing question to see how smaller countries tend to have a larger propensity to import shares. Thus, for examining the extent to which technology trade affect productivity I must control for country size. In the second column of Table 4 I regress those components and I see how technology import share depend negatively of area and population. Although population is not significant, the area is significant at 1 per cent, confirming the presumption that larger countries tend to import less technology. The third column I add the fitted technology import share and the model gain in explanatory power. Moreover, size measures are negative and both are significant. The coefficient for the instrumental variable is lower but keeps a high significant level. This mean that is preserve enough information on observed technology import share to yields only moderated standard errors by instrumental variable estimation. The corresponding *F*-statistic on excluded instrument is 20.86 and is large enough to discard a likely finite sample bias of 2SLS estimate towards OLS.

Figure 5 plot the partial association between the observed and the fitted technology import share once controlled for population and area. The relationship is slightly weaker but still positive and the effect of the two outliers is stronger. Figure 6 represents the same information once excluded R&D performing economies. The resulting subsample seems more appropriate to identify technology imports with technology investment as documented by Eaton and Kortum (2001) and Caselli and Wilson (2003), given the fact that only the group of R&D performing economies produces and exports the overall capital goods and equipment. The correlation between the technology imports observed and its instrument once controlled by size is even stronger.

3. Technology imports, productivity and growth

The aim of the paper is to account for the effect of technology imports on productivity and growth. Following our estimation strategy, the purpose of the former exercise was to obtain a variable correlated to the technology import variable but independent of the residuals of the productivity equation. Using directly the observed import share would bias the estimation. Hence I must use the exogenous variable instead of observed trade in the productivity equation and estimate by two stage least squares.

Productivity is a function of overall size and technology imports as specified in Equation (2). This decomposition of productivity may appear simple, *a priori*, because it omit others potential determinants of productivity and push them into the error term. As is argued by Frankel and Romer (1999), if the geographic approach to the instrument is correct, there is no reason for additional exogenous determinants of productivity to be correlated with the instrument. Moreover, the inclusion of other variables on the estimation would not account for the overall effect of technology imports on productivity leaving out any effects operating through its impact on these variables.

3.1 ESTIMATING THE EFFECT ON PRODUCTIVITY

Table 5 reports the coefficients of equation (2) using population and area as measures of size plus a constant. The first and the second columns include the estimation results for 90 sample countries. And the third and fourth columns include only 69 developing economies. All the estimations confirm the positive effect of technology imports on productivity. The first regression shows that controlling for size, an increase of one percentage point in technology import share increase GDP per worker 0.24 per cent, but the result is only marginally significant (*t*-statistic is 1.78). Size affect productivity in a confusing way, while area has a negative coefficient population has a positive influence, however neither are significant.

The second column show the result estimated by two stages lest squares (2SLS) technique using as instrument the fitted technology import share derived from the gravity model of trade. The coefficient imply that technology imports effect on productivity are six time stronger than in OLS estimation and is significant at 1 per cent level of confidence controlling for country size. Hence, an increase of one percentage point in the technology import share raises productivity by 1.45 per cent. Moving from OLS to 2SLS increases the effect of technology imports on productivity but also increase the standard error of the coefficients. Hence, I perform the Hausman (1978) test of exogeneity and the hypothesis of equality between OLS and 2SLS is rejected.

Sizes measures are positive and significant at 10 per cent level of confidence. An overall increase in population and area of one percent increases productivity by 0.6 percent. These facts support the view that scale effects are important not only in producing technologies but also in adopting foreign technologies.

The third and fourth exclude OECD economies and represent a subsample of non-R&D performer countries. OLS estimates are in the third column. The magnitude of the effect of technology imports on productivity is similar to that obtained in the wider sample and is significant only at 10 per cent level of confidence. The fourth column show 2SLS coefficient and the technology import share is significant and five times larger than OLS. This implies that an increase of one percentage point in the technology import share raises productivity by 1.16 per cent. Once again OLS estimations understate the effect on productivity. However, in this smaller subsample I cannot reject the hypothesis of equality between OLS and 2SLS coefficients.

The effect of size on productivity is confusing in OLS because population is positive and not significant but area is negative and significant (*t*-statistic = 1.94). Moving to 2SLS size's effects are positive and significant in both measures at 10 per cent level. The overall estimate effect of increasing population and area by one percent is an increase of productivity by 0.3 per cent. This is again a fact that supports the view of scale effects on international technology adoption.

3.2 ROBUSTNESS

To check the robustness of the results I perform a battery of proofs. First, as it is shown above, I have considered a general sample of countries and a subsample of developing economies to examine the parameter stability. Second, it is possible that some outliers have a great influence on the relationship between the observed and the fitted technology import shares. Removing the Netherlands and Belgium the effect of technology imports on productivity by OLS change little, however the 2SLS coefficient rises to 2.25 (t = 2.92). Another possible outlier may be Singapore because it has a high observed import share given its size. Dropping all those countries the OLS does not change and the 2SLS coefficient rises to 2.04 (t = 3.36). Dropping the Netherlands, Belgium and Singapore is equivalent to estimate using the developing countries subsample, so there is no noticeable change.

Third, it is a serious concern that different countries located in a given geographic situation perform systematically better than others and these differences are explaining the results. Rodriguez and Rodrik (2000) and Irwin and Tervio (2000) suggest that previous studies evaluating the effect of trade on income such as Frankel and Romer (1999) are not robust to the inclusion of latitude as a explanatory variable. To evaluate this concern I include continental dummies and reestimate regressions in Table 5. Under OLS and 2SLS the coefficients are lower and the standard errors rise. In both samples, the constructed technology imports coefficient still is above the actual technology imports coefficient. And excluding the outliers the difference between OLS and 2SLS estimates increases. I use and alternative way to address this concern. I include latitude (distance to the equator) as an explanatory variable in equation (2). Latitude is an indicator that measures climate influences, for instance, it may proxy resource endowments such as arable land, or likelihood of suffer from tropical diseases such as malaria. But also it measures omitted influences related to the distance to the equator, such as western influence. I report the estimation results in Table 6. OLS and 2SLS coefficients are slightly smaller in the general sample, although they remain significant as in Table 5. Latitude appears to capture any positive and significant effect. In the developing economies subsample the OLS coefficient does not change and the 2SLS coefficient rises to 1.27, keeping a highest significant level but the latitude coefficient is null. Thus, there is evidence of systematic differences among regions, and those differences appear to be captured by the variable latitude. Moreover, none of those differences appear to alter the relationship between technology imports and productivity. It is an open debate to give an economic interpretation to this evidence. In some sense latitude is a proxy of western influence as Hall and Jones (1999) interpret, but also it may be a proxy for climate adverse effects or poor infrastructure. The null effect of latitude in the developing countries subsample is obviously driven by the absence of the highest productivity countries, so latitude is capturing omitted factors common to the OECD economies.

3.3 CHANNELS THROUGHOUT TECHNOLOGY TRADE AFFECT PRODUCTIVITY

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

$$(6)\ \log y_i = \frac{\alpha}{1-\alpha}\log\left(\frac{K_i}{GDP_i}\right) + \log h_i + \log A_i$$

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 term.

The exercise consist in regress each component of y on the technology import share, both measures of size and a constant considering the trade variable exogenous (OLS) and endogenous (2SLS). I consider the same dataset as Hall and Jones (1999) used[5]. Unfortunately merging both dataset there are three observations lost in the general sample. On a priori grounds one expect to find a strong correlation between

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

technology imports and physical capital, because importing technology is a way of accumulate new capital goods, as stressed by the traditional growth theory. Additionally, it is expected to find a high correlation between technology imports and the index of neutral technology, as it is emphasized by the technology diffusion literature.

Table 7 show the estimation results of the level accounting exercise. For all the components 2SLS are higher than OLS coefficients. It is worth noting that technology imports raise GDP per worker through each component. OLS estimates indicates that that capital deepening is affected by technology imports in a moderate way, human capital is also affected with a lower coefficient and finally total factor productivity is not clearly affected. Moving toward 2SLS estimation, the transmission channels become inverted and all the coefficients are significant at 1 per cent. The higher impact of technology trade is on total factor productivity, then on human capital and finally on capital depth. An increase of one percentage point in the technology import share raises total factor productivity, human capital and capital depth by 0.7, 0.4 and 0.35 per cent respectively. Furthermore, controlling for technology trade, country size plays a positive role in each productivity transmission channel. The overall effect of an increase in area and population of one percentage point is an increase on 0.3, 0.17 and 0.13 in total factor productivity, human capital and physical capital respectively.

The standard errors under the 2SLS estimation are higher than under OLS estimation. The hypothesis of equality between coefficients is tested and it is rejected in each component. So OLS tend to bias downwards the effect of technology imports on each component of income per worker.

3.4 ESTIMATING THE EFFECT ON GROWTH

The next step is to evaluate the effect of technology imports over a growth decomposition of GDP per worker. For this purpose I break down the GDP per worker in 1995 into different components as follows:

$$(7)\ \log\left(\frac{GDP}{W}\right)^{1995} = \log\left(\frac{GDP}{W}\right)^{1965} + \left[\log\left(\frac{GDP}{W}\right)^{1995} - \log\left(\frac{GDP}{W}\right)^{1965}\right]$$

Where the first term on the right hand side is the productivity level at the beginning of the period and the second term is the long term growth rate of income per worker.

These terms are regressed against a constant, the technology import share, the log of the area and the log of the population.

Table 8 reports the results of OLS and 2SLS estimations in the general sample and in the developing countries subsample. In the general sample, technology imports have a positive effect on initial productivity level and, again, the 2SLS coefficient is higher. However, the growth effect over the period is positive but not significant. An increase of one percentage point in the technology import share increase long term growth by 0.02 per cent in the OLS estimation and 0.32 in the 2SLS estimation. Also, controlling for technology imports size has an overall positive effect on the two productivity terms. In the developing countries subsample, the effect on initial productivity level is positive and higher under the instrumental variable estimation. The growth effects are null under the OLS but positive and significant under 2SLS (*t*-statistic = 1.71). An increase of one percentage point in the technology import share rise long term growth by 1 per cent in developing economies. Moreover, size exerts an overall positive influence on productivity growth controlling for technology imports.

3.5 ASSESSING THE BIAS

A serious concern is whether OLS is downward biasing the estimates. In theory, high productivity economies have more domestic resources and infrastructures to overcome the cost of distance and tend to import more. Moreover, high productivity countries have better institutions to reduce the informational search cost linked to international trade activities. And also, trade policies that encourage technology imports and raise productivity may be correlated to other sound policies enhancing productivity. All these reasons lead to positive correlation between the technology import share and the error term in the equation (2), and bias upwards OLS estimates of technology trade on productivity. However, what it is found in that 2SLS estimates are higher than OLS by large and in some cases the differences are statistically significant. How to explain this puzzle?

One possible explanation comes from the presence of measurement errors in variables. Productivity or technology trade data are likely to be recorded with measurement errors. In this case OLS estimation would be downward biased. Another source of measurement error arises because the using of proxy variables. It may be possible that R&D intensive goods imports averaged over a long period is an imperfect measure for proxying R&D spillovers or technology flows between countries, as prescribe endogenous growth literature. Under this situation OLS coefficient will be also downward biased. Unfortunately, to distinguish empirically between one and another measurement error is not possible.

4. Conclusion

This paper argues that the correlation existing between technology imports and productivity cannot be interpreted as evidence supporting the idea that trade (in R&D intensive products) increases productivity. Importer behavior is not determined exogenously and ordinary regressions would produce biased estimates. To address this problem I have constructed an instrumental variable based on geographic components of technology imports. Distance between countries, climate or isolation are variables not affected by productivity, income level or policy and this fact reveal them to be appropriate candidates for deducing an instrument for technology trade.

Productivity is affected by inward and outward economic interactions. Prior studies have detected that outward interactions comes mainly from trade in R&D intensive products. The fact that capital goods are produced and exported in a handful of countries support the view that technology import share is a good proxy for investment in embodied technologies specially in developing economies. To the extent in which this trade is determined by geography I get consistent estimates of the effects of technology trade on productivity.

Results showed technology imports increase productivity in the general sample and in the developing economies subsample. The relation of geographic component of technology imports imply that an increase in 1 percentage point in the technology import share over the period 1965 and 1995 raises productivity by 1.45 and by 1.16 per cent in both samples respectively. Additionally, scale variables such as area and population have been found as positively related to productivity. This fact supports the view that controlling for trade variable, size is an important variable for productivity. The results are robust to the exclusion of outliers, and to the inclusion of latitude. The effects are estimated with great precision in the general sample; however it is not possible to reject the hypothesis of equality between the OLS and the 2SLS coefficients in the developing countries subsample.

The findings also suggest that technology imports increase GDP per worker enhancing the total factor productivity term, as suggested by the endogenous growth and the technology diffusion literatures. Moreover, human capital and capital depth are spurred by technology imports, although to a less extent. Long term growth is also affected by technology imports. A rise of one percentage point in technology import share increase growth by 1 per cent in the developing economies subsample. The size exert a positive effect, populated countries tend to grow faster when technology trade is controlled for.

This evidence raises questions about the growth effects of trade policy in developing countries. While geography impose natural barriers to economies far from technological leaders import substitution policies have created still larger barriers for developing economies with long term effects. Trade promoting policies drawn to attract foreign technologies may overcome geography's adverse effects that have a level effect on productivity, but also they have an effect on productivity growth. To understand this phenomenon requires further investigation about the dynamic effects of learning and adopting technologies from abroad.

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Table 1: Technology exports (in % of GDP)

	1965	1970	1975	1980	1985	1990	1995
Australia	0.2	0.4	0.6	1.0	1.0	1.1	1.0
Austria	0.3	0.6	0.9	1.6	2.0	1.8	1.7
Belgium-Luxembourg	2.3	3.9	5.5	6.7	10.3	9.0	9.6
Canada	0.7	0.7	0.8	1.5	1.2	1.2	2.0
Switzerland	3.5	4.6	4.5	5.1	5.9	6.0	6.8
Germany	1.6	2.0	2.3	2.7	3.7	3.1	2.7
Denmark	0.9	1.3	1.3	1.7	2.3	2.2	2.5
Spain	0.3	0.3	0.4	0.7	1.1	0.9	1.3
Finland	0.2	0.4	0.5	1.0	1.4	1.2	1.7
France	0.9	1.1	1.4	1.7	2.4	2.1	2.5
United Kingdom	1.1	1.4	2.0	2.0	2.5	2.2	2.9
Greece	0.1	0.2	0.4	0.4	0.3	0.4	0.3
Ireland	0.4	1.2	2.4	4.8	7.7	8.9	15.7
Italy	0.6	0.7	1.1	1.2	1.2	1.0	1.6
Japan	0.3	0.4	0.6	0.5	0.5	0.5	0.5
Netherlands	3.0	4.3	5.5	6.2	8.8	7.9	7.2
Norway	1.6	1.5	1.6	1.7	1.8	2.0	2.0
New Zealand	0.5	0.7	0.3	0.9	1.4	1.1	1.7
Portugal	0.5	0.6	0.7	0.7	1.7	1.2	1.0
Sweden	0.6	0.7	1.0	1.3	1.9	1.8	2.8
United States	0.3	0.4	0.6	0.8	0.5	0.7	0.9
Arithmetic Average	**0.9**	**1.3**	**1.6**	**2.1**	**2.8**	**2.7**	**3.3**

Source: COMTRADE and World Bank (2001).

Note: Exports are *c.i.f.* values

Table 2: Technology trade, productivity and growth

#	Code	Country	Area (in thousands of km^2)	Population (in thousands)	Actual Technology import share	Fitted Technology import share	Real GDP per worker	Growth GDP per worker
1.	ARG	Argentina	2780	34768	0.8	0.3	24738	0.5
2.	AUS	Australia	7741	18072	1.0	0.5	45331	1.4
3.	AUT	Austria	84	8047	2.4	1.9	45023	2.7
4.	BEL	Belgium	33	10137	4.9	7.1	50154	2.1
5.	BEN	Benin	113	5475	1.4	0.6	2205	0.3
6.	BFA	Burkina faso	274	9988	1.2	0.4	1804	1.6
7.	BGD	Bangladesh	144	119768	0.6	1.2	6092	1.9
8.	BHS	Bahamas	14	.	5.4	2.5	.	.
9.	BLZ	Belize	23	217	3.9	2.0	18843	.
10.	BOL	Bolivia	1099	7414	1.3	0.4	6635	-0.6
11.	BRA	Brazil	8547	159346	0.9	0.4	18479	2.4
12.	BRB	Barbados	0	264	3.6	2.2	28075	3.0
13.	CAF	Central Afr.R.	623	3288	1.5	0.4	2298	-1.5
14.	CAN	Canada	9971	29354	1.2	1.6	45021	1.1
15.	CHE	Switzerland	41	7041	3.0	3.1	44289	0.5
16.	CHL	Chile	757	14210	1.5	0.4	21990	1.8
17.	CIV	Ivory Coast	322	13528	2.1	0.6	4888	1.1
18.	CMR	Cameroon	475	13182	1.9	0.6	3765	0.1
19.	COL	Colombia	1139	38558	1.9	0.9	12070	0.9
20.	CRI	Costa rica	51	3333	3.4	1.4	13783	0.4
21.	CYP	Cyprus	9	733	3.5	2.0	34653	4.1
22.	DNK	Denmark	43	5222	2.4	3.0	44352	1.3
23.	DOM	Dominican rep.	49	7823	1.9	1.4	11847	2.1
24.	ECU	Ecuador	284	11460	2.1	1.0	12729	2.1
25.	EGY	Egypt	1001	58180	1.9	0.9	12345	2.2
26.	ESP	Spain	506	39223	1.3	1.5	40981	2.5
27.	ETH	Ethiopia	1104	56530	1.2	0.9	1217	0.0
28.	FIN	Finland	338	5108	2.1	1.6	38189	2.1
29.	FJI	Fiji	18	770	2.7	1.7	15425	1.6
30.	FRA	France	552	59326	1.4	2.9	44901	2.2
31.	GBR	U.K.	245	58612	1.5	2.7	39699	1.7
32.	GER	Germany, West	357	81661	1.4	2.4	42529	.
33.	GHA	Ghana	239	17075	2.5	0.6	2644	1.0
34.	GMB	Gambia	11	1111	2.8	1.0	2311	0.4
35.	GRC	Greece	132	10454	1.7	1.6	30644	2.2
36.	GTM	Guatemala	109	9976	2.6	1.3	13184	1.5
37.	GUY	Guyana	215	830	4.7	1.0	7165	0.0
38.	HKG	Hong Kong	1	6156	4.5	2.5	51042	5.5
39.	HND	Honduras	112	5654	3.4	1.3	6653	0.4
40.	HTI	Haiti	28	7168	1.5	1.3	3493	.
41.	HUN	Hungary	93	10229	3.5	1.9	21384	.
42.	IDN	Indonesia	1905	193976	1.5	0.8	9276	4.5
43.	IND	India	3288	929358	0.5	0.7	5065	2.7
44.	IRL	Ireland	70	3601	4.8	3.4	44791	3.4
45.	ISL	Iceland	103	267	2.7	1.2	37457	1.2
46.	ISR	Israel	21	5545	2.3	1.4	42969	2.4
47.	ITA	Italy	301	57301	1.5	1.5	50605	2.8
48.	JAM	Jamaica	11	2522	4.1	2.1	7696	-0.2
49.	JOR	Jordan	89	4195	2.6	1.2	16253	1.3
50.	JPN	Japan	378	125570	0.4	0.6	36733	3.8

51.	KEN	Kenya	580	27216	3.1	0.8	2563	1.0
52.	KOR	Korea, rep.	99	45093	2.6	2.8	32538	5.9
53.	LBR	Liberia	111	.	2.4	0.7	.	.
54.	LKA	Sri lanka	66	18112	1.6	1.0	7372	2.6
55.	MAR	Morocco	447	26386	1.8	1.2	10798	1.3
56.	MDG	Madagascar	587	13300	1.6	0.5	1895	-0.6
57.	MEX	Mexico	1958	90903	1.1	0.8	20947	0.8
58.	MLI	Mali	1240	9705	1.3	0.4	1692	-0.9
59.	MLT	Malta	0	371	5.1	3.5	34284	.
60.	MUS	Mauritius	2	1122	2.2	0.9	25052	3.4
61.	MWI	Malawi	118	9757	2.0	0.4	1577	1.5
62.	MYS	Malaysia	330	20610	2.7	1.1	24800	4.0
63.	NER	Niger	1267	9150	0.7	0.3	1706	-1.8
64.	NIC	Nicaragua	130	4426	3.9	1.3	5848	-2.4
65.	NLD	Netherlands	41	15460	3.5	5.3	44763	1.2
66.	NOR	Norway	324	4358	1.9	1.9	48168	2.2
67.	NPL	Nepal	147	21272	0.5	0.7	2977	1.9
68.	NZL	New zealand	271	3656	2.6	0.8	36956	0.1
69.	PAK	Pakistan	796	122375	1.7	0.8	6822	3.3
70.	PAN	Panama	76	2631	2.2	1.3	15187	1.7
71.	PER	Peru	1285	23532	1.4	0.6	10226	-0.8
72.	PHL	Philippines	300	70267	1.9	1.4	7568	0.8
73.	PNG	Papua n.guinea	463	4301	2.1	1.3	7543	1.1
74.	POL	Poland	323	38588	1.4	2.3	16373	.
75.	PRT	Portugal	92	9917	2.7	1.6	28981	2.9
76.	PRY	Paraguay	407	4828	0.7	0.3	12243	1.4
77.	SDN	Sudan	2506	.	1.2	0.6	.	.
78.	SEN	Senegal	197	8330	2.3	0.8	3051	-0.5
79.	SGP	Singapore	1	3526	6.8	2.1	39186	4.7
80.	SLB	Solomon is.	29	.	2.6	1.7	.	.
81.	SLV	El salvador	21	5669	3.1	1.6	13395	0.4
82.	SOM	Somalia	638	.	1.6	0.6	.	.
83.	SWE	Sweden	450	8827	2.0	1.7	39802	1.1
84.	SYC	Seychelles	0	75	2.0	1.4	21395	3.9
85.	SYR	Syria	185	14112	1.8	1.2	15984	2.4
86.	TCD	Chad	1284	6707	0.8	0.3	2574	-0.6
87.	TGO	Togo	57	4110	2.1	0.8	2176	-0.4
88.	THA	Thailand	513	59401	2.5	1.0	12763	5.0
89.	TUN	Tunisia	164	8958	2.4	1.9	16788	2.4
90.	TUR	Turkey	775	61646	1.4	1.1	14101	2.6
91.	URY	Uruguay	177	3218	1.4	0.5	19671	1.1
92.	USA	U.S.A.	9364	263073	0.3	0.6	56065	1.5
93.	ZAF	South africa	1221	39120	1.8	0.4	21336	0.8
94.	ZAR	Zaire	2345	43848	0.9	0.3	655	-3.8
95.	ZMB	Zambia	753	8980	1.7	0.3	2436	-1.7

Notes: Area and Population are from World Bank (2001). Actual and fitted Technology import share as explained in the text (in % of GDP). Real GDP per worker in 1995 at international prices (dollars) is from Penn World Table 6.1 (RGDPWOK) (updated version of PWT 5.6 by Summer and Heston (1991). Growth of GDP per worker is the annual average growth rate over 1965 and 1995 (in %).

Table 3. Bilateral Technology Imports

	Log of Technology Imports	
	Coefficients	Interaction terms
Constant	-24.38**	8.87**
	(1.10)	(2.14)
Log of distance	-1.08**	0.13
	(0.07)	(0.21)
Log of importer area	-0.10**	0.14
	(0.02)	(0.09)
Log of exporter area	-0.31**	0.02
	(0.03)	(0.09)
Log of importer population	-0.02	-0.40**
	(0.03)	(0.11)
Log of exporter population	1.71**	-0.29**
	(0.04)	(0.11)
Landlocked (importer)	-0.41**	0.05
	(0.09)	(0.30)
Landlocked (exporter)	1.20**	-0.26
	(0.14)	(0.36)
Longitude (importer)	0.01**	
	(0.00)	
Longitude (exporter)	0.01**	
	(0.00)	
Latitude (importer)	-0.01**	
	(0.00)	
Latitude (exporter)	0.11**	
	(0.01)	
Observations	48725	
Adjusted R-squared	0.54	

Robust standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 4. First Stage Regression

	(1)	(2)	(3)
Technology imports share	0.66**		0.41**
	(0.10)		(0.09)
Log of Area		-0.33**	-0.19**
		(0.06)	(0.06)
Log of Population		-0.09	-0.17*
		(0.08)	(0.07)
Constant	1.29**	7.02**	5.54**
	(0.17)	(0.56)	(0.60)
Observations	90	90	90
R-squared	0.34	0.48	0.57
F-test			20.86

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 5. Technology Imports and Productivity

	(1) OLS Full Sample	(2) 2SLS Full Sample	(3) OLS No OECD Sample	(4) 2SLS No OECD Sample
Technology imports share	0.24	1.45**	0.23	1.16**
	(0.14)	(0.43)	(0.13)	(0.42)
Log of Area	-0.11	0.30	-0.17	0.15
	(0.09)	(0.18)	(0.09)	(0.17)
Log of Population	0.15	0.26	0.11	0.15
	(0.10)	(0.14)	(0.09)	(0.13)
Constant	8.79**	0.31	9.57**	3.44
	(1.19)	(3.15)	(1.09)	(2.93)
Observations	90	90	69	69
Hausman test		8.93		5.31
p-value		0.03		0.15

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 6. Technology Imports and Productivity

	(1) OLS Full Sample	(2) 2SLS Full Sample	(3) OLS No OECD Sample	(4) 2SLS No OECD Sample
Technology imports share	0.19	1.02**	0.23	1.27**
	(0.13)	(0.35)	(0.13)	(0.44)
Log of Area	-0.05	0.21	-0.16	0.17
	(0.09)	(0.14)	(0.09)	(0.18)
Log of Population	0.06	0.16	0.10	0.16
	(0.10)	(0.12)	(0.10)	(0.14)
Latitude	0.02**	0.01*	0.00	-0.00
	(0.00)	(0.01)	(0.01)	(0.01)
Constant	8.85**	3.05	9.56**	2.78
	(1.13)	(2.56)	(1.10)	(3.02)
Observations	90	90	69	69
Hausman test		6.64		6.10
p-value		0.16		0.19

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 7. Technology Imports: Transmission Channels

	(1) OLS Full Sample	(2) 2SLS Full Sample	(3) OLS Full Sample	(4) 2SLS Full Sample	(5) OLS Full Sample	(6) 2SLS Full Sample
Technology imports share	0.10**	0.35**	0.07	0.41**	0.02	0.69**
	(0.04)	(0.11)	(0.04)	(0.12)	(0.08)	(0.26)
Log of Area	0.04	0.12**	0.01	0.13*	-0.13*	0.09
	(0.02)	(0.04)	(0.02)	(0.05)	(0.05)	(0.11)
Log of Population	-0.01	0.01	0.02	0.04	0.16*	0.20*
	(0.03)	(0.03)	(0.03)	(0.04)	(0.06)	(0.08)
Constant	-0.36	-2.09**	0.19	-2.15*	8.17**	3.59
	(0.32)	(0.78)	(0.32)	(0.89)	(0.72)	(1.88)
Observations	87	87	87	87	87	87
Hausman test		6.14		8.41		7.35
p-value		0.10		0.04		0.06

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 8. Technology Imports: Growth Decomposition

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Full Sample				Non-OECD Sample			
	Log $(GDP/W)^{1965}$		Growth GDP/W		Log $(GDP/W)^{1965}$		Growth GDP/W	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Technology imports share	0.21	1.32**	0.02	0.32	0.19	0.82*	-0.01	1.04
	(0.12)	(0.39)	(0.19)	(0.42)	(0.11)	(0.32)	(0.22)	(0.61)
Log of Area	0.09	0.46**	-0.66**	-0.56**	0.06	0.27*	-0.80**	-0.44
	(0.08)	(0.16)	(0.12)	(0.18)	(0.07)	(0.13)	(0.14)	(0.25)
Log of Population	-0.07	-0.01	0.70**	0.72**	-0.13	-0.13	0.80**	0.81**
	(0.09)	(0.13)	(0.14)	(0.14)	(0.08)	(0.10)	(0.16)	(0.19)
Constant	8.10**	0.55	2.95	0.90	8.71**	4.74*	3.60	-3.02
	(1.04)	(2.79)	(1.62)	(3.05)	(0.90)	(2.14)	(1.80)	(4.06)
Observations	84	84	84	84	64	64	64	64
Hausman test		9.17		0.63		4.37		3.43
p-value		0.03		0.89		0.22		0.33

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Figure 1: Development and technology specialization

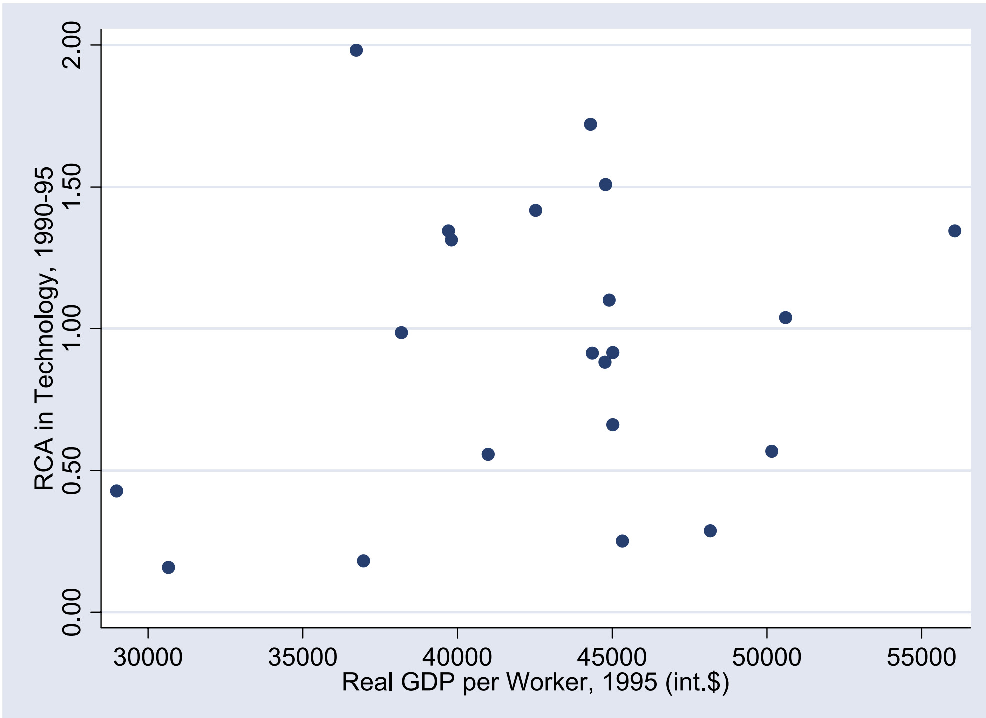

Figure 2: R&D and technology specialization

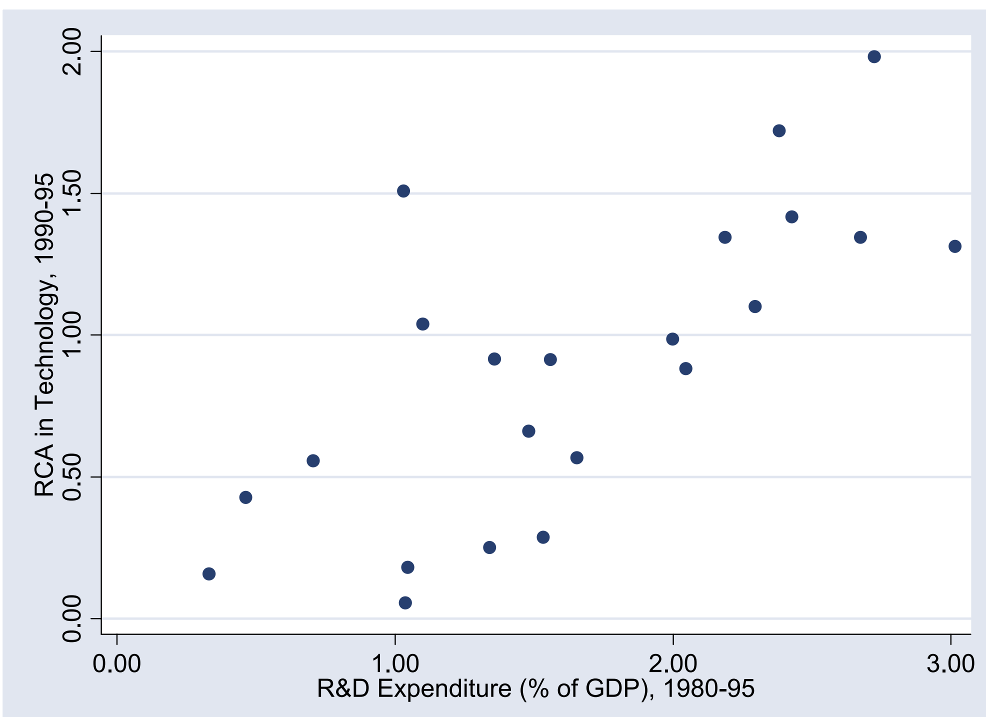

Figure 3: Growth and technology imports, 1965-1995

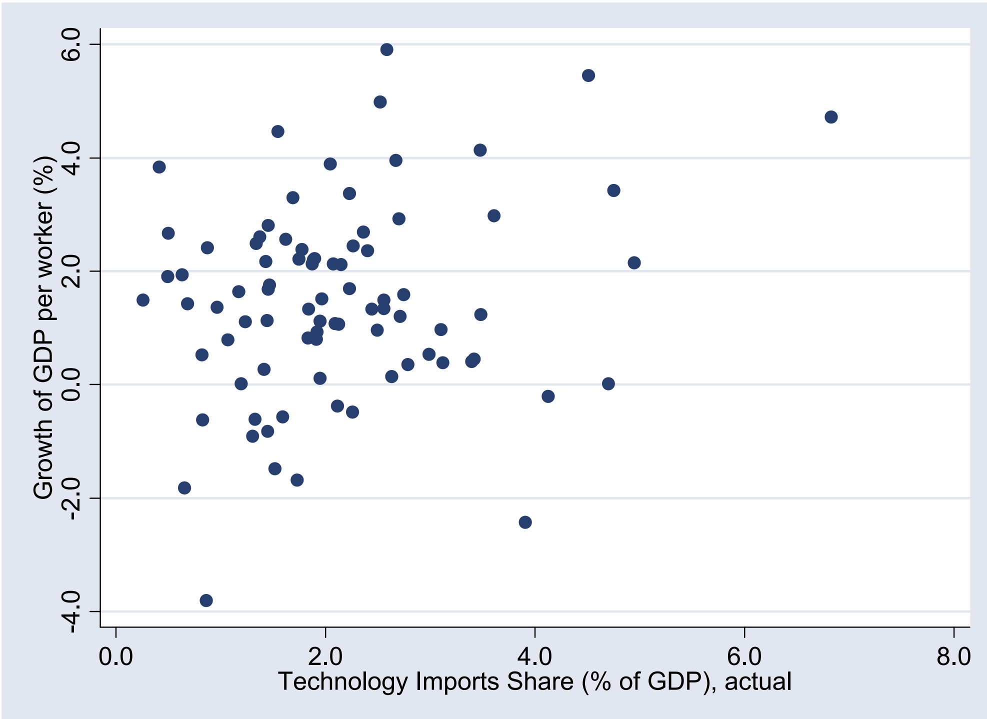

Figure 4: Technology imports observed vs. estimated

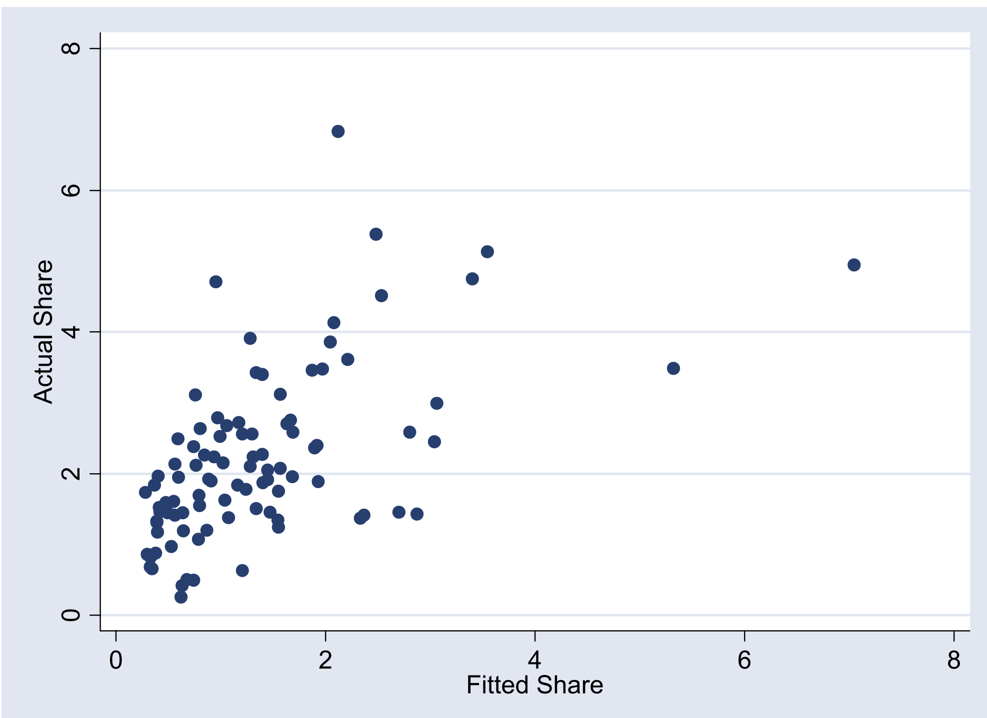

Figure 5: Partial association between technology imports observed and estimated

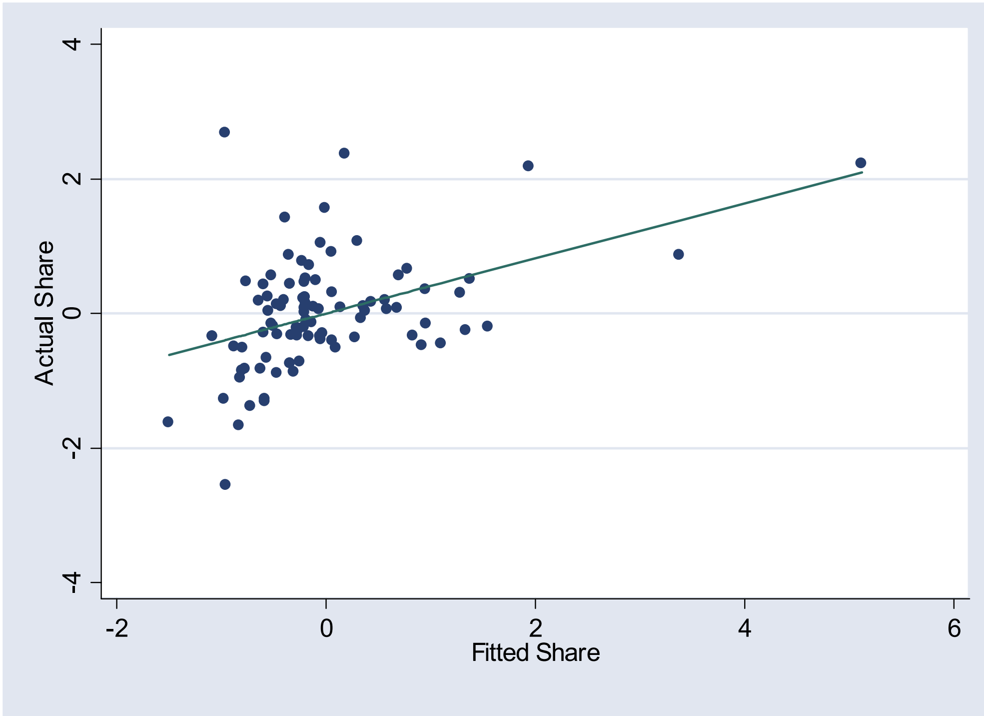

Figure 6: Partial association between technology imports observed and estimated, Non-OECD