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R&D SPILLOVERS AND EXPORT PERFORMANCE:

EVIDENCE FROM THE OECD COUNTRIES

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Abstract

Recent empirical literature on trade performance has emphasised the role played by domestic R&D in boosting international competitiveness. These models, based on technology-related theories of trade, find empirical support for this hypothesis. In this paper we go further and test whether trading partners' R&D has a positive effect on domestic exports through trade-related international R&D spillovers. We find support for the hypothesis that R&D spillovers increase competitiveness of the trading partners. This has important implications for recent theories of growth that emphasise the role of international trade as the main factor promoting technology diffusion and growth.

Keywords: R&D spillovers, export functions, panel cointegration.

JEL Classification Numbers: F10, O31, C22, C23

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1. Introduction

There is little doubt that exports are an important factor in explaining the long-run growth performance of countries and regions. Recent empirical evidence in Frankel and Romer (1999) and Marin (1992) has found support for this hypothesis, as did earlier attempts by Balassa (1978) and Michaely (1977). Several explanations have been given for this phenomenon, from the externalities effect of Feder (1982) to the demand oriented model of Thirlwall (1979) and the recent endogenous growth models summarised in Grossman and Helpman (1991) and Aghion and Howitt (1998). These latter models have emphasised the effect of trade as the vehicle for a faster diffusion of knowledge from frontier to laggard countries through trade-related R&D spillovers.

On the other hand, empirical studies on technological factors affecting trade have found a strong impact of domestic innovation efforts on competitiveness – see, for instance, Fagerberg (1988) and Soete (1981). Product and process innovation seems to be a crucial factor in gaining market share in international markets at least in those concerning developed countries.

In this paper we try to combine both pieces of evidence and analyse whether trade related international R&D spillovers are an important factor determining exports. In other words, we try to answer the question of whether R&D efforts in one country affect positively the exports of its trade partners through technological diffusion. As we shall see later, this is a more accurate specification for testing the technology gap trade theory. On the other hand, if R&D

spillovers are shown to be an important determinant of exports this has interesting implications for growth modelling. This is because the link between trade and growth may well not stop at the first generation effect from trade to growth.

The paper is organised as follows. Section 2 discusses the theoretical motivation for this empirical exercise and its implications. Section 3 describes the specification and data, and discusses the panel cointegration techniques in which the estimations are based. Section 4 comments on the empirical results, and section 5 concludes.

2. R&D Spillovers, Trade and Growth

In their very influential paper, Coe and Helpman (1995) (C-H hereafter) provide evidence on the extent and importance of R&D spillovers for explaining productivity growth. Although evidence is provided only for OECD advanced countries, Coe *et al*. (1997) also find a significant impact of spillovers on less developed countries arising from R&D performed in advanced countries. They use a simple framework to prove their point. C-H estimate the total factor productivity level (TFP) as a function of domestic and foreign R&D. Foreign R&D is defined as an import share weighted average of the R&D of the trading partners of a particular country. They find evidence that both domestic and foreign R&D have a positive and significant impact on TFP. This impact is higher the higher the degree of openness of the country. Hence, if a country increases its degree of openness, its trade partners increase their R&D stock or the country's import share from technologically advanced countries increases, the country's TFP will increase.

Their theoretical background relies on Grossman and Helpman (1991) although it can also be derived from Rivera-Batiz and Romer (1991). The argument runs as follows. In the simple case of horizontally differentiated intermediate inputs, the theory assumes that factor productivity depends on the number of intermediate inputs used in the production process. This is because of the increasing division of labor due to Smithian specialisation. Firms seeking monopoly rents will perform R&D to create new intermediate inputs. Since aggregate output will depend on a measure of the available number of inputs, TFP will depend on the cumulative past investment in R&D. In a closed economy the argument stops there. However, in the case of an open economy in which output is internationally traded, TFP will depend not on the domestic R&D capital stock but on the world's. Trade will ensure that two economies do not produce the same intermediate inputs. That is, trade allows economies to use a wider range of production inputs and hence achieve higher levels of efficiency. In the most plausible scenario in which economies have both traded and non-traded goods, TFP will depend on both domestic and foreign R&D capital stocks. In other words, trade is a source of growth because it allows countries to enjoy inputs of production from its trading partners. Although this way of modelling R&D spillovers is probably the more fashionable, trade will also enhance productive efficiency by allowing the contact with different organisational and managerial structures and the use of reverse engineering.

Evidence for these models is reviewed by Navarreti and Tarr (2000). They conclude that the import related R&D spillovers hypothesis finds strong support in the empirical literature.[1] Keller (2000) also finds strong support using micro data at the firm level. Keller's results show not only that the spillovers related to importing activities are important for boosting

[1] As mentioned earlier, the main source for aggregate level evidence is Coe and Helpman (1995). Further evidence can be found in Kao *et al*. (1999).

productivity but also that small countries tend to enjoy higher spillovers as well as countries with a higher share of intermediate goods in total imports. Hakura and Jaumotte (1999) also show that these spillovers are more related to trade within industries and between firms.

Although most studies have concentrated on the effects of imports on TFP, exports can also be a channel of knowledge transmission. Firms selling in the international market have access to new technologies and products and also can engage in quicker learning-by-doing by specialising in products with large market potential. Although the evidence on these grounds is not as strong as with imports,[2] this may be due to the micro nature of the data. Firm level studies tend to ignore the fact that at the macro level the gains can be higher because of substantial positive spillovers from exporter firms to the rest of the economy as reported by Aitken *et al*. (1997). Hence, exports can also be a source of knowledge spillovers and aggregate learning affecting productivity levels. Of course, from a different perspective, exports have the important role of relaxing international payments constraints allowing for higher imports without incurring balance of payments crises (Thirlwall, 1979). In this sense exports are necessary to afford the foreign technology contained in intermediate input imports.

All the theory and evidence discussed above sets out a strong relation between trade and productivity growth through technological knowledge flows. In this sense, this literature provides a quite useful piece of information and establishes a starting point for our empirical exercise. This branch of the literature, however, concentrates on the effects of trade-related spillovers on growth in what seems to be a rather unidirectional relationship. This is an understandable simplification for models would be analytically intractable otherwise.

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[2] See, for instance, Pack (1993) and Bernard and Jensen (1999) and Aw *et al*. (2000).

However, it is our aim to look at the impact that technological flows have on trade performance itself. By doing so we open up the models to a richer set of dynamics relating trade to technology and growth. The obvious candidate to examine when we try to analyse the latter link is the technology-gap trade theory.

Technology-based theories of trade have long emphasised the role of innovation and technological differences in determining the pattern of trade. The first attempt to do so is Posner's (1961) technology-gap trade model later extended by Hufbauer (1966). For Posner, countries placed at the technological frontier would enjoy an export advantage in technologically advanced products. This advantage, however, is only temporary. Since knowledge is a public good, it is free to flow to less advanced countries. This flow is subject to both demand and imitation lags. The former refers to the time it takes for the consumers to respond to the appearance of a new or cheaper product. The latter is related to the reaction capacity of foreign producers to adapt their production structure in order to produce the new goods with cheaper labour.[3] Another significant branch of models relating technological differences and trade is the product cycle model of Vernon (1966) and Hirsch (1974). Although from a different perspective, the conclusions of this model are very similar to those of the technology-gap model. Innovation in leader countries generates new products that pass through different stages of maturity. Initially the new good is only produced by the innovator country. Once the good has reached a standardisation phase, the production localises in backward countries whose labor costs are lower. Foreign direct investment plays a crucial role here in the diffusion of technical knowledge. More recently, Krugman (1979, 1986) develops formal models of technology-gap trade. His conclusions are similar to those of previous

[3] Hufbauer's (1966) model focuses on learning-by-doing as the main factor determining the imitation lag, since successful production of new goods requires a certain degree of accumulated experience.

models, but he also concludes that diffusion will cause an improvement in both exports and the terms of trade in laggard countries.

Although the theoretical models considered only one leader and follower countries, the picture of the world economy is considerably more complex. In reality we have a group of countries (roughly the G7) that are capable of performing most of the innovations in the world, together with a group of close catchers and finally a set of countries lagging behind. From this it is obvious that exports in one country will depend on the R&D domestically performed and on the R&D of its trade partners. Although there may be long adoption lags, the steady state picture would be one in which exports will depend on the rate of innovation at home and that of the trading partners.

The majority of the empirical studies on the technological factors affecting trade performance find strong evidence that domestic innovation is an important variable.[4] Most of the studies on technology-gap theories concentrate on the effects of innovation on a sectoral basis as opposed to the country-wide empirical approach to test endowment theories (Wakelin, 1998). Examples of these studies finding positive effects of innovation on relative export performance include Soete (1981, 1987), Dosi *et al*. (1990), Greenhalgh *et al*. (1994), Magnier and Toujas-Bernate (1994) and Wakelin (1998). Cotsomitis *et al*. (1991) found only weak evidence on the effect of innovation. Few attempts have analysed the effect of innovation on aggregate export performance. An exception is Fagerberg (1988) who finds that innovation and investment play a crucial role in explaining competitiveness for a set of 15 OECD countries. Although the sectoral studies give a more precise and detailed analysis of

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[4] Regardless of whether we use input or output innovation measures.

the factors driving export performance, aggregate studies are a better approach to understand the world's changing pattern of trade by country.

A remark should be made at this point. Despite the fact that the technology-gap theories of trade insist on both innovation and diffusion as determinants of trade, none of the studies mentioned above take into account the effect that innovation in trading partners has on domestic exports. A close look at all the technology-based theories of trade will indicate that countries that do not perform R&D will nonetheless export goods at a lower stage of the technological ladder. That is, aggregate exports, regardless of the composition, will depend on the innovation efforts made abroad. It is the stock of past and present knowledge flowing from frontier to backward countries that allow the latter to enjoy growing exports as the frontier countries innovate. The recent advance in this area in growth theory and empirics can prove to be quite useful when analysing trade performance.

The rest of this paper will be devoted to analysing the aforementioned point. What is the importance of trade related technology spillovers in determining export performance? As discussed earlier, previous empirical work on growth has focused on the effect of trade as the channel of R&D spillovers affecting *productivity*. The empirical work on trade only takes domestic R&D as the relevant innovation variable affecting exports. Here we analyse whether R&D investment performed by trading partners is also an important factor determining trade performance. We do so by taking a simple but informative approach adapting the C-H methodology to estimate export functions for 21 OECD countries for the period 1970-1990.

3. Specification, Data and Estimation

3.1 Specification

The common specification of an export demand function contains basically two arguments: relative prices and world income. The former tries to capture price competitiveness while the latter is a normalisation variable accounting for other factors affecting export performance. According to this, the logarithmic version of an export demand function can be expressed as:

$$X_t = a + bRER_t + cZ_t \tag{1}$$

where X_t is the level of real exports, RER_t is the real exchange rate as a proxy for relative prices and Z_t is the world's income. All variables are expressed in logs unless stated otherwise. In recent years some authors have introduced innovation as another argument in the export demand function accounting for non-price competitiveness arising from research activities. This is the usual specification in empirical applications of technology-based trade theories. In our specifications we will test both the influence of domestic R&D and that of foreign R&D. Given the nature of the data, especially for R&D, and the problems involved by estimating the equations in levels, the regressions will be run using pooled data for all the 21 OECD countries involved using recent panel cointegration techniques. We estimate four specifications of the export demand function:

$$X_{it} = a_i + bRER_{it} + cZ_{it} + dSD_{it} \tag{i}$$

$$X_{it} = a_i + bRER_{it} + cZ_{it} + dSD_{it} + eSF_{it} \tag{ii}$$

$$X_{it} = a_i + bRER_{it} + cZ_{it} + dSD_{it} + e(m_{it}SF_{it}) \tag{iii}$$

$$X_{it} = a_i + bRER_{it} + cZ_{it} + dSD_{it} + e(m_{it}SF_{it}) + f(G7SD_{it}) \tag{iv}$$

where *i* is a country index, *SD* is domestic R&D capital stock, *SF* is foreign R&D stock, *m* is the fraction of imports relative to GDP (not in logs) and *G*7 is a dummy variable for the more advanced Group of Seven OECD countries. Note that each country has a different intercept term to allow for country-specific time-invariant fixed effects.

Equation (i) is the basic specification for testing the effect of domestic R&D on export performance as commented earlier. Since our estimations are in levels, we take as the relevant innovation variable the stock of accumulated R&D from C-H. We assume, for theoretical consistency, that the level of exports depends on accumulated knowledge rather than on the flow of new innovations. Equation (ii) introduces the stock of foreign R&D to measure the extent to which technological spillovers affect a country's exports. Note that the coefficient e in equation (ii) may capture two effects. The first is the technology diffusion effect that we would expect to have a positive impact on a country's exports. The second one is a competition effect. Since most of the exports are intra-OECD, an increase in foreign R&D stock can have a negative impact insofar as the exports of two countries may be competing for market share. The net effect will determine the sign of the foreign R&D coefficient. The foreign R&D capital stock is an import share weighted average of the R&D stocks of a country's trading partners. Hence, diffusion of knowledge will depend not only on the extent to which trading partners innovate, but also on the relative importance of trading partners. That is, trade with the US will lead to a higher degree of diffusion than with, say, Portugal or Greece. A problem with this measure of foreign R&D capital stock is that it treats closed and open economies equally. However, it is obvious that the degree of international openness will also affect the extent of knowledge spillovers. In order to account for this problem we estimate equation (iii) in which we have interacted SF_{it} with the import-GDP ratio m_{it}. This is the preferred way of measuring the impact of foreign technology, since it accounts for the extent to which the country has contact with international markets and uses foreign intermediate inputs. Another advantage of this specification is that we can obtain country-specific time-varying foreign R&D elasticities. Finally, in equation (iv) we introduce an interaction term between domestic R&D stock and a dummy for the G7 countries to allow for different elasticities of domestic R&D between the seven largest economies and the rest of the OECD countries considered. This is because we would expect the G7 economies to have a larger reward on their R&D because of larger markets allowing for better opportunities to innovate and higher complementarities between R&D activities.

3.2 Data

We estimate equations (i) to (iv) for a panel of 21 OECD countries for the period 1971 to 1990. The countries used for estimation are: United States, Japan, Germany, France, Italy, United Kingdom, Canada, Australia, Austria, Belgium, Denmark, Finland, Greece, Ireland, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden and Switzerland. We excluded Israel from the C-H sample due to the lack of comparable data for some of the export demand function variables. The period of estimation was chosen on the basis of availability of R&D capital stock data, which is taken from C-H. Although it would be possible to extend their calculations to more recent years, we decided not to in order to ensure consistency of the data throughout the period and comparability with the results obtained in C-H.

All the data except for the innovation variables and the import shares matrix are taken from the OECD Statistical Compendium (1997). Exports are defined as the real value in local currency of exports of goods and services. World income is defined as the sum of the income of the 21 OECD countries in constant 1991 US$ PPPs, minus the income of country *i*:

$$Z_i = \sum_{j=1}^{21} Y_j \quad \text{with} \quad j \neq i$$

The RER_{it} variable is the export price divided by the import price of goods and services times the effective nominal exchange rate. The import-GDP ratio is real imports of goods and services divided by real GDP at the same base year. Domestic R&D stock is taken from C-H. It is calculated using the R&D expenditures and applying the perpetual inventory method, using an estimated initial value for the R&D stock. Finally, foreign R&D is calculated multiplying the bilateral import shares matrix times the domestic R&D stock for each country. This gives us a 21×20 matrix with the stock of foreign R&D for each one of the countries over time. Since Israel was taken out of the sample, we adjusted the import weights matrix given in C-H.

Following Lichtenberg and van Pottelsberghe (1998), we do not transform the R&D variables into index numbers. Although exports are measured in local currencies and *Z, SD* and *SF* are measured in constant US$ PPPs, the effect of using different currencies would be captured by the country-specific fixed effects. Transforming the R&D variables into index numbers would generate a problem. Taking equation (iii) and assuming that we index *SD* and *SF* at 1991 = 1, we would have (all variables in logs):

$$\begin{aligned} X_{it} &= a_i + bRER_{it} + cZ_{it} + d(SD_{it}/SD_{i91}) + e(m_{it}(SF_{it}/SF_{i91})) \\ &= a_i + bRER_{it} + cZ_{it} + dSD_{it} - dSD_{i91} + em_{it}SF_{it} - em_{it}SF_{i91} \end{aligned} \quad (2)$$

It is clear that the last term of (2) is not time invariant and cannot be incorporated in the country-specific fixed effects. The estimation of *e* in (2) would not be equivalent to that in (iii) using levels data and thus (2) would be misspecified if we estimate it using index numbers and fixed effects.

3.3 Estimation

In this section we review the estimation techniques used to obtain the relevant parameters of the model. We estimate the model in levels, since we are interested in the long-run determinants of exports and the impact of foreign technology is subject to diffusion lags. This fact poses some difficulties because the time series component of the panel may not be stationary, and there is the possibility of obtaining spurious relations amongst the variables. One possibility to control for this problem is to run separate regressions for each country using the different well-known cointegration techniques. There are two problems with this. First, the limited number of observations in our panel makes it difficult to make inferences about the presence of unit roots or cointegration relations of the variables. Both due to this shortage and the small sample period, all the tests developed in time series literature suffer from low power. This could lead us to accept the null of a unit root or no cointegration when the alternative is true. Secondly, estimating the model using time series data will leave us with few degrees of freedom to make inference, especially in models like ours in which we can have up to 5 independent variables. Using the recently developed panel cointegration techniques we can increase the power of the tests and the degrees of freedom by combining cross-section and time series information.[5] This is, of course, at the expense of not allowing for much heterogeneity between the different cross-sections of the panel but the mere fixed effects.[6] Three aspects of the estimation procedure are relevant here: testing for unit roots, testing for cointegration and estimating the long run vector.

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[5] See Banerjee (1999) for an overview of the literature on panel data unit roots and cointegration.

[6] There is the possibility of allowing for a very high degree of heterogeneity in the panels by using the so-called mean group estimators (e.g. Pesaran and Smith, 1995). Given the nature of our data we prefer to use pooled estimators although we impose stronger restrictions as a result.

Several tests have been proposed to check whether or not the panel series have a unit root. Two of them – Breitung and Meyer (1994) and Levin and Lin (1993) – assume that the autoregressive coefficient of the variable is equal across cross-sections. A third and less restrictive test is due to Im *et al*. (1997) in which the autoregressive parameters are allowed to differ under the alternative. The three tests are based on the *ADF* regression:[7]

$$\Delta x_{it} = \alpha_i + \rho_i x_{it-1} + \sum_{j=1}^{p_i} \gamma_{ij} \Delta x_{it-j} + \xi_{it} \tag{3}$$

The Breitung and Meyer (1994) (BM) test assumes $\rho_i = \rho \; \forall \, i$ and $\gamma_{ij} = \gamma_j \; \forall \, i$ and tests for $H_0 : \rho = 0$. They show that the t-statistic for the null hypothesis is asymptotically $N(0,1)$ as $N \to \infty$. The validity of this test is lower the larger the time dimension *T*. Levin and Lin (1993) (LL-93) propose a panel *ADF* test that allows for individual specific time trends and short run dynamics. The LL-93 test allows for a higher degree of heterogeneity of the cross-sections and also for a more general correlated and heteroskedastic structure of the errors. LL-93 derive the asymptotic distributions of the panel estimator of ρ under different degrees of heterogeneity.[8] They propose a transformation of the t-statistic for $H_0 : \rho = 0$ against $H_A : \rho_i = \rho < 0$. As is the norm for panel unit root tests, the adjusted t-statistic t_{p*} converges to a $N(0,1)$ as $T, N \to \infty$.

Finally, the Im *et al*. (1997) (IPS) panel unit root test is based on the null of non-stationarity ($H_0 : \rho_i = 0 \; \forall \, i$) against the alternatives $H_A : \rho_i < 0$, $i = 1, ..., N_1$; $\rho_i = 0$, $i = N_1 + 1, ..., N$. Note that the IPS test does not assume that all cross-sectional units converge towards the equilibrium value at the same speed under the alternative, i.e. $\rho_1 = \rho_2 = ... = \rho_N < 0$, and thus

[7] For simplicity we will ignore deterministic trends in the explanation of the tests.
[8] We refer to Levin and Lin (1993) for details on these transformations.

is a less restrictive test than the LL-93. The IPS test is based on the standardised *t*-bar statistic as follows:

$$\Gamma_t = \frac{\sqrt{N}[\bar{t}_{NT} - \mu]}{\sqrt{v}} \sim N(0,1) \qquad (4)$$

where $\bar{t}_{NT}$ is the average of the N cross-section $ADF(p_i)$ *t*-statistics, μ and v are, respectively, the mean and variance of the $ADF(p_i)$ statistic under the null, tabulated by Im *et al*. (1997) for different *T*s and lag orders of the *ADF* test. Im *et al*. (1997) also show that under the null of a unit root, Γ_t converges to a $N(0,1)$ as $N/T \to k$ (*k* is any finite positive constant).

We now turn to the panel cointegration tests. We follow Kao (1999) and Pedroni (1999) who provide a set of panel cointegration tests under different assumptions about the cointegration vector. Two families of tests can be identified. The first is the family of panel tests in which we assume the same autoregressive coefficient for the errors of the cointegration equation. These tests are only valid if the long run cointegrating vector is assumed to be the same for the different cross-sectional units although allowing for heterogeneity in the intercepts and time trends. The second family is the group mean approach. In this case, cointegration tests are based on transformations of the average of the individual unit root tests, thus allowing for a high degree of heterogeneity in the panel. It is easy to see that, in the case of *ADF* tests, the first family is equivalent to the BM and LL-93 unit root tests and the second to the IPS test. Since we are assuming equal slope coefficients in our long-run vector, we will focus on the first set of panel tests.

We will use three tests for cointegration. The first two are *DF* tests and the third an *ADF* test to allow for serial correlation in the errors of the equation, following Kao (1999).[9] The *DF* tests can be calculated from the estimated OLS residuals as:

$$\hat{e}_{it} = \gamma \hat{e}_{it-1} + u_{it} \tag{5}$$

The null is $H_0 : \gamma = 1$ against $H_A : \gamma < 1$. Two *DF* type tests can be calculated from this regression:

$$DF_\gamma = \frac{\sqrt{N}T(\hat{\gamma}-1)+3\sqrt{N}}{\sqrt{10.2}},$$

$$DF_t = \sqrt{1.25}t_\gamma + \sqrt{1.875}N .$$

Finally, the *ADF* test augments (5) with the lagged values of the first difference of the errors. Applying the transformation proposed by Kao (1999) to the t-statistic of γ in the augmented regression we can test for cointegration allowing for autocorrelated errors. The three statistics converge towards a $N(0,1)$.

Regarding the estimation of the long-run cointegration vector, we rely on Kao and Chiang (1998) who discuss the properties of the OLS, Fully Modified (FM) and dynamic OLS (DOLS) estimators. Kao and Chiang (1998) find that the OLS fixed effects estimation of the panel is subject to a non-negligible bias in finite samples. For this reason, they propose two alternative estimators. The FM estimator, as in Pedroni (1996), shows better performance, as it is asymptotically normal with zero bias.[10] The other proposed alternative is the DOLS estimator based on Stock and Watson (1993). It is obtained running the following regression:

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[9] Pedroni (1999) also provides non-parametric versions of these tests equivalent to the Phillips-Perron procedure for individual time series.

[10] The FM estimator removes nuisance parameters due to autocorrelation and heteroskedasticity.

$$y_{it} = \alpha_i + \beta x_{it} + \sum_{j=1}^{p} \eta_j \Delta x_{i,t-j} + \sum_{j=1}^{p} \zeta_j \Delta x_{i,t+j} + e_{it} \qquad (6)$$

Hence, the DOLS regression adds to the OLS the leads and lags of the differences of the independent variables. This ensures asymptotically unbiased estimates and avoids the estimation of nuisance parameters. Kao and Chiang (1998) also show that the DOLS estimator is preferable to both the OLS and the FM for finite samples. We will report both the OLS and the DOLS estimations of our four specifications of the export demand function with R&D spillovers.

4. Results

The procedure followed to obtain the elasticities of interest is similar to the Engle-Granger procedure in single time series estimations. First, we test for the existence of unit roots. If the series are I(1) we then test if they are cointegrated in the long run by applying cointegration tests on the residuals of the OLS fixed effects regression. Finally, we obtain the parameters of interest estimating the long-run vector using both OLS and DOLS.

Table 1 reports the three panel unit roots tests mentioned in the previous section for all the variables used in the model. Where we had to choose the number of lags of the *ADF* test we did so by using the general to specific procedure proposed by Hall (1990). It is easy to see that in all but one case, the tests indicate that the variables involved in the regression are non-stationary. Note that both the LL-93 and IPS tests have been applied to the original series minus the cross-sectional mean. This is to account for the possible existence of dependence between the cross-sectional units. The rejection of the null in the BM test of Z_{it} may be due to the fact that this variable, by construction, is subject to a high degree of cross-sectional dependence.

Table 2 contains the three panel cointegration tests applied to the OLS residuals of equations (i) to (iv). Except for the DF_{γ} test in equations (i) and (ii), the rest of the tests show that the null of no cointegration is strongly rejected. These results indicate that there is a long run relationship between the level of exports and the rest of independent variables included in the models.

The estimation results are reported in Tables 3 and 4. Although the t-statistics of the OLS regression are not reliable due to the aforementioned bias, we report them in order to compare the results with the DOLS estimation. A surprisingly positive result is that both methods of estimation yield very similar results. This indicates that our specifications are robust to the estimation method. Only the elasticities of domestic R&D are consistently and considerably lower in the OLS regression. The signs and sizes of the parameters on the traditional export function variables (*Z* and *RER*) are as expected. We find a low but statistically significant relative price effect on exports, and an income elasticity in the range of one.[11] The impact of domestic R&D is clearly positive and significant in all the specifications with an elasticity of around 0.25 for the DOLS estimation. However, note that the elasticity of domestic R&D is substantially higher for the G7 group as shown in equation (iv), with an elasticity close to 0.5.

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[11] Usually the estimated income elasticity of exports is higher than one for the majority of OECD countries except the US and UK. However, when we include innovation variables its size will be reduced. This is because the export income elasticity may capture many of the non-price competitiveness factors affecting exports, including innovation.

This result supports previous studies finding a significant impact of innovation on trade performance.[12]

Regarding foreign R&D the results for equation (ii) show that this variable has a negligible impact on export performance in the OECD countries. This may be due to the combination of the diffusion and competition effects commented earlier on. However, when we take into account the degree of openness of the economy as in (iii) and (iv), foreign R&D becomes a positive and statistically significant variable. Foreign R&D, through trade-related innovation spillovers, has a long-run positive impact on the level of exports. Although this impact seems to be smaller than the domestic return to R&D, this indicates that the direction and amount of trade with technologically advanced countries is a relevant factor in explaining the success of the exporting sector of an economy. We calculated foreign R&D elasticities for each country and three years (1971, 1980 and 1990) as reported in Tables 5 and 6 using the OLS and DOLS results for equation (iv). The elasticities were obtained by multiplying the coefficient on mRF times the degree of openness. Overall the results show that the elasticity is higher the smaller the size of the economy due to the higher degree of openness. Another important result is that the impact of R&D spillovers has increased in recent years. Amongst the smaller economies, Belgium and Ireland seem to be the most sensitive to foreign R&D, whereas Australia and Finland seem to be the less sensitive.[13] Spain and Greece experienced the highest increase in the foreign R&D elasticity from 1971 to 1990. Although the magnitude of the impact may not seem to be important, for some countries this is as high as the effect of relative price changes, and the effect shows an upwards trend in recent years. Also, we cannot

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[12] Our results are not comparable to previous studies because we make use of R&D capital *stocks* and use aggregate data instead of sectoral data. Nevertheless, other studies such as Wakelin (1998) report similar elasticities using pooled industry data and country dummies.

[13] This may indicate that spatial distance is also a relevant variable to understand the degree of technology diffusion as found in Vamvakidis (1998).

forget that the competition effect may be covering a stronger impact on export performance through technology diffusion. Nevertheless, domestic R&D still has a stronger impact on export performance.

5. Concluding remarks

In this paper we have analysed the impact that international R&D spillovers have on the export performance of 21 OECD countries. The question has important implications for both trade and growth theory. Technology-based trade theories emphasise the effect that catching-up has on determining the trade pattern of countries. However, empirical applications of these theories do not test directly the effect that innovation arising in frontier economies has on the follower ones. On the other hand, although growth theory and empirics has taken into account the direct effect of R&D spillovers on productivity, they have tended to ignore its possible effect on growth through improved competitiveness.

We have attempted to analyse this impact by using an approach that draws on that used in Coe and Helpman (1995) to estimate long-run export demand functions. Our results are just aggregate magnitudes and would require further consideration and analysis especially making use of sectoral data. In any case, clear patterns arise from our empirical exercise. First, domestic R&D is a very important factor determining exports in advanced economies. The impact of domestic innovation is considerably higher in the technologically advanced countries. Second, although its impact is lower than that of domestic R&D, trading partners' R&D has a positive and significant impact on export performance. That is, countries importing more from technologically advanced countries or with a higher degree of openness seem to benefit from their stock of knowledge. Finally, this impact seems to be stronger in small economies and increasingly important in recent years.

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Table 1: Panel Unit Roots Tests

	Unit Root Test:		
Variable	BM	LL-93	IPS
X	0.022	2.651	-0.881
Z	**-7.653**	1.848	0.500
RER	1.417	5.465	-0.720
SD	0.798	4.200	0.929
SF	3.002	6.546	-0.663
mSF	1.660	5.932	3.346

Notes:
1. The BM test is based on Breitung and Meyer (1994). The LL-93 is the modified panel unit root test of Levin and Lin (1993). The IPS test is based on Im *et al*. (1997). The number of lags and deterministic trends has been selected following Hall (1990).
2. Bold characters denote the rejection of the null of a unit root at the 5% level (critical value –1.64).

Table 2: Panel Cointegration Tests

	Panel Cointegration Test:		
	DF_γ	DF_t	ADF_t
Equation (i)	-0.868	**22.614**	**-2.186**
Equation (ii)	-0.975	**22.598**	**-2.563**
Equation (iii)	**-2.056**	**22.261**	**-2.437**
Equation (iv)	**-3.590**	**22.020**	**-3.021**

Notes:
1. All the tests were performed on the residuals of the OLS regression.
2. The DF_γ, DF_t and ADF_t tests are from Kao (1999) and Pedroni (1999) (see text). The number of lags for the *ADF* test has been selected following Hall (1990)
3. Bold characters denote the rejection of the null of no cointegration at the 5% level.

Table 3: Export Function Estimation using OLS

Variable	Equation (i)	Equation (ii)	Equation (iii)	Equation (iv)
Z_{it}	1.322 (27.844)	1.609 (11.063)	1.172 (21.042)	0.991 (17.136)
RER_{it}	-0.066 (-4.217)	-0.065 (-4.160)	-0.080 (-5.194)	-0.112 (-7.413)
SD_{it}	0.181 (8.427)	0.184 (8.607)	0.189 (9.031)	0.191 (9.687)
$G7SD_{it}$				0.214 (7.328)
SF_{it}		-0.090 (-0.807)		
$m_{it}SF_{it}$			0.045 (4.844)	0.062 (6.847)
$N \times T$	420	420	420	420
$\bar{R}^2$	0.998	0.998	0.998	0.998

Notes:
1. The OLS estimations are based on pooling data for the 21 countries for the period 1971-1990. t-ratios in parenthesis.
2. All equations include unreported country specific fixed effects.

Table 4: Export Function Estimation using DOLS

Variable	Equation (i)	Equation (ii)	Equation (iii)	Equation (iv)
Z_{it}	1.208 (19.647)	1.699 (9.430)	1.031 (14.807)	0.862 (12.299)
RER_{it}	-0.052 (-2.970)	-0.040 (-2.327)	-0.060 (-3.494)	-0.094 (-5.401)
SD_{it}	0.239 (8.353)	0.250 (8.589)	0.252 (9.065)	0.254 (9.637)
$G7SD_{it}$				0.224 (6.079)
SF_{it}		-0.102 (-1.025)		
$m_{it}SF_{it}$			0.050 (4.853)	0.070 (6.987)
$N \times T$	357	357	357	357
$\bar{R}^2$	0.998	0.998	0.998	0.999

Notes:
1. The DOLS estimations are based on pooling data for the 21 countries for the period 1971-1990. One lag and one lead of the differenced independent variables are used to estimate the dynamic model. t-ratios in parenthesis.
2. All equations include unreported country specific fixed effects.

Table 5: Elasticity of Exports with respect to Foreign R&D using the OLS estimates of Equation (iv)

	1971	1980	1990
United States	0.0041	0.0043	0.0063
Japan	0.0047	0.0051	0.0062
Germany	0.0114	0.0138	0.0159
France	0.0114	0.0140	0.0167
Italy	0.0080	0.0090	0.0118
United Kingdom	0.0110	0.0126	0.0166
Canada	0.0107	0.0141	0.0192
Australia	0.0079	0.0087	0.0108
Austria	0.0166	0.0226	0.0286
Belgium	0.0290	0.0365	0.0434
Denmark	0.0213	0.0208	0.0226
Finland	0.0130	0.0141	0.0151
Greece	0.0092	0.0103	0.0184
Ireland	0.0251	0.0293	0.0337
Netherlands	0.0244	0.0270	0.0305
New Zealand	0.0116	0.0139	0.0168
Norway	0.0245	0.0210	0.0210
Portugal	0.0189	0.0175	0.0258
Spain	0.0074	0.0100	0.0157
Sweden	0.0133	0.0145	0.0169
Switzerland	0.0181	0.0248	0.0294

Table 6: Elasticity of Exports with respect to Foreign R&D using the DOLS Estimates of Equation (iv)

	1971	1980	1990
United States	0.0047	0.0049	0.0071
Japan	0.0054	0.0058	0.0070
Germany	0.0130	0.0157	0.0180
France	0.0129	0.0159	0.0190
Italy	0.0091	0.0102	0.0133
United Kingdom	0.0125	0.0143	0.0188
Canada	0.0121	0.0160	0.0218
Australia	0.0090	0.0099	0.0123
Austria	0.0188	0.0256	0.0324
Belgium	0.0329	0.0414	0.0492
Denmark	0.0241	0.0236	0.0256
Finland	0.0147	0.0160	0.0172
Greece	0.0105	0.0116	0.0208
Ireland	0.0285	0.0333	0.0382
Netherlands	0.0277	0.0306	0.0346
New Zealand	0.0132	0.0158	0.0190
Norway	0.0277	0.0239	0.0238
Portugal	0.0214	0.0198	0.0293
Spain	0.0084	0.0114	0.0178
Sweden	0.0151	0.0165	0.0192
Switzerland	0.0206	0.0281	0.0333