Competitiveness, Scale and R&D

by Jan Fagerberg,
Norwegian Institute for International Affairs (NUPI), PO. Box 8159 DEP, 0033 Oslo

Abstract

The purpose of this study is to explore the relationship between competitiveness, scale and R&D with the held of OECD databases and the ongoing work in the OECD on embodied technology flows. The analysis is based on data for ten OECD counteies and 22 industries in 1985. The results suggest that both direct R&D and R&D acquired indirectly through purchase of capital goods and intermediates have a significant, positive impact on competitiveness. Indirrect R&D from domestic sources appears to be more conducive to competitiveness than indirect R&D from aboard. On average the total (direct and indirect) impact of a given investment in R&D on exports is about twice as large as the impact of an investment of similar size in physical capital. The impact of R&D investment appears to be especially high in large countries and R&D intensive industries.

Introduction [1]

Recent theorising on growth and trade points to the importance of R&D and spillovers from this to other firms, industries and countries. According to this literature the geographical boundaries of such spillovers are of prime importance for trade patterns. Country size may also play an important role. However, until recently applied work in this area has had relatively little to say about of these issues. This paper starts by a short review of the theoretical and applied literature in this area. Based on the lessons an eclectic model is formulated and applied to data for ten OECD countries and twenty industries in 1985. The data set includes among other things data for direct R&D and R&D acquired indirectly through purchase of capital goods and intermediary products. The results give some support to theories that focus on the importance of R&D investments and spillovers for exports.

The agenda

The interest in the relation between technology and competitiveness dates back to the so-called neo-technological trade theories of the 1960s (technology gap, product cycle etc., for an overview see Dosi and Soete, 1988). These may be seen as attempts to overcome the rigidity of the standard neoclassical approach to international trade, which had become apparent for many observers. Most of these attempts were, explicitly or implicitly, based on Schumpeter's analysis of innovation and diffusion as the driving forces behind the competitiveness of firms (and economic growth in general).[2] Writers in this tradition pointed to the importance of R&D and innovation for trade flows and possible differences across industries and countries in this respect.

Since this issue was first introduced by Posner (1961), Vernon (1966) and others, economic theory has changed considerably. Trade theorists started to apply the insights from models of imperfectly competitive markets to the analysis of international trade and world-wide competitiveness (so called 'new trade theory', see Helpman 1984 for an overview). In this literature the existence of fixed costs, such as, for instance, investment in R&D, plays an important role (since they give rise to economies of scale). Thus, following this approach, R&D investment may be an important competitive factor. The size of the domestic market also plays an important role in such models. One possible outcome in a world characterised by imperfect competition, economies of scale and trading costs (that are neither too small, nor prohibitive) is other things being equal that countries specialise in products for

[1] This paper is based on data supplied by the OECD Directorate for Science, Technology and Industry (DSTI) as part of project there. I am grateful to the DSTI for allowing me to use them for this paper . An earlier version was presented at the conference "Technology and International Trade" in Oslo, October 6-8, 1995. I wish to thank the participants, in particular the commentator and my fellow editors, for comments and suggestions.

[2] See Dosi, Pavitt and Soete (1990) for an elaboration and empirical application of this perspective.

which there is a relatively large domestic market, the so-called "home-market effect"(Krugman 1990). Furthermore, if some industries are characterised by economies of scale while others are not, one might expect the large countries to specialise in the former and the small countries in the latter. However, as shown by Melchior in this volume, in general the predictions for trade patterns in such models depend very much on the specific assumptions made in each case. Still, the suggestions emphasised above are quite frequent in this literature. They also carry a lot of intuitive support. Many would probably side with Krugman when he notes about one of these suggestions "that, upon reflection, looks at though it ought to be more general than the particularity of the assumptions might lead one to believe." (Krugman, 1990, p. 82)

More recently, growth theorists started to introduce the Schumpeterian insight of the importance of innovation-diffusion into formal growth models based on the assumption of imperfectly competitive markets (so called 'new growth theory, for an overview see Grossman and Helpman 1995). These models also point to importance of R&D for growth of GDP and exports. While much of the earlier literature in this area emphasised the direct impact of the R&D effort of a firm, industry or country, the new growth literature focuses more sharply on the impact of diffusion or 'technological spillovers'. Following this approach, it matters a lot what the actual boundaries of these spillovers are. If technological spill-overs are (mainly) national in scope, a large country will benefit more from investments in new technology (R&D) than a small one. Hence, on this assumption, a large country should be considered more likely to gain a competitive advantage in R&D intensive activities than a small country.

Differences across countries in the efficiency of R&D and other technological activities have also been emphasised by the recent literature on 'national system of innovation' (Lundvall et al. 1992, Nelson et al. 1993). This literature stresses the systemic aspects of innovation, the importance of interaction across firm, industries and sectors and the advantage of a coherent national system in this area. A related perspective is that of Porter (1990), who also emphasises the potential beneficial effects of close links and interaction between producers and their (domestic) customers and suppliers, so-called "clustering" or "agglomeration".[3] This phenomenon is also consistent with a perspective that focuses on scale economics, for instance among domestic suppliers of goods and services, see Venables (1994). What is of interest here is that all these approaches suggest that a high reliance of domestic sources of technology may imply a competitive advantage.

The evidence

Empirically, analysts have tried to highlight the relation between competitiveness and technology by regressing a measure of export performance on

[3] See Fagerberg (1995b) for an empirical test of the relationship between export performance and the strength of advanced domestic users.

a technology variable, usually based on R&D or patent statistics, and – in some cases – other variables that were deemed relevant for the analysis. Generally, the relation is the following:

(1) X = f (T, O),

where X is a measure of export performance, T is a technology proxy and O is a set of other variables.

A distinction may be made between cross-sectional work, using data for a number of industries and countries at one point in time (the static case), and applications on time-series data (the dynamic case). Among the former Lacroix and Scheuer (1976), Walker (1979), Soete (1981, 1987), Dosi and Soete (1983), Dosi, Pavitt and Soete (1990) and Fagerberg (1995a) may be mentioned. Generally, the results of these studies support the hypothesis of a positive relation between competitiveness and technological activity for a large number of industries, not only those that are commonly regarded as 'high tech'. However, tests that use R&D in stead of a patent-based technology indicator tend to come up with a more narrow list of industries for which technology matters. This was also confirmed by Fagerberg (1995a) who used both set of indicators. Some of these studies also included a variable assumed to reflect scale factors (population). But – with the exception of Fagerberg (1995a) – the reported results are difficult to assess, since several of the variables included in these tests to some extent reflect scale factors. Fagerberg (1995a), in a cross-sectional study of 19 OECD countries and 40 industries, found scale factors to be important in a few industries only (electronics, cars, aircraft and power generating machinery). The industries for which scale was found to be an important factor covered around one fifth of total OECD trade.

A dynamic version of (1) was suggested by Fagerberg(1988) and applied to pooled cross-sectional time-series macro-data for a number of industrialised countries. Time-series estimates for the macro-level have also been presented by Amendola et al. (1993). In general, these exercises confirm the importance of technology for trade performance. Greenhalgh (1990) and Greenhalgh et al. (1994) did time series analyses at the industry level, but only for the UK. Magnier and Toujas-Bernate (1994) and Amable and Verspagen (1995) both analysed pooled time-series and cross-sectional data for five large OECD countries in the 1970s and 1980s. In contrast to the previous literature in this area, these studies also allowed for differences in the impact of variables across countries. However, inter-industry differences seemed to dominate (with a possible exception for Japan). Generally, the results from these studies confirm much of the previous evidence from cross-sectional samples, but the role of scale factors was largely ignored.

Data and method

The applied literature surveyed above has generated a lot of insights and knowledge on the impact of R&D and innovation (and other factors) on trade performance across countries and industries. However, many questions remain open, in particular those related to the possible impact of technology flows across firms, industries and countries. The purpose of this paper is to add to the existing literature in this area by exploring the relation between competitiveness, scale and R&D with the help of the OECD STAN and ANBERD Data Bases and the recent work by the OECD on embodied technology flows. The ensuing data set is unique in the sense that it provides data for a number of variables – including direct R&D and R&D acquired through purchase of capital goods and intermediates – at the level of the industry (mostly in current prices).

Ten countries, 22 industries[4] and (roughly) two decades are included. We excluded two industries on the grounds that they were ill defined (two residual categories) . For some of the technology variables data were available for selected years only (in some cases only one year). This made a regular time-series difficult. What will be presented here is a cross-sectional analysis for 1985, the only year for which the technology variables are available for all ten countries (even then about five per cent the observations are missing due to lack of data for certain variables, industries and countries). Another option that may be explored in future work is to construct a panel, combining information from several years. This, however, will only be possible for a subset of countries and/or variables.

International competitiveness may be defined as the ability to sell goods and services on international markets in competition with suppliers from other countries. Exports seem to be a natural indicator for that, and most of the applied literature on competitiveness also use an export-based indicator.[5] The model we wish to apply is an eclectic one in which the international competitiveness of a country at the industry level, measured through its exports, is explained by technological factors (direct R&D efforts and its the ability to profit from R&D acquired indirectly through purchase of inputs, whether of domestic or foreign origin), cost competitiveness (wage-level), the rate of investment and the size of the domestic market, or more formally:

(2) $X = f\ (RD, DIF, FOR, INV, WAGE, HOME)$,

where;

X is exports ,
RD (Direct R&D) is business enterprise R&D ,
DIF (Indirect R&D) is R&D acquired indirectly through purchases of capital goods and intermediate goods from domestic and foreign suppliers ,

[4] See the appendix for a complete listing of products/industries.

[5] There may be different ways to handle the data (deflation etc.), see the section on results for how this is done.

FOR (Foreign share) is indirect R&D acquired through purchases of capital goods and intermediate goods from foreign suppliers as a percentage of total indirect R&D (both foreign and domestic),
WAGE is labour costs per worker,
INV is gross fixed capital formation,
HOME is domestic demand (measured as production+imports-exports).

All variables are measured in current prices in a common currency (US dollars) and are country and industry specific. The data for R&D acquired through purchases of capital goods and intermediates were calculated by the OECD and supplied as shares of production (these data were then scaled up by using data for production in 1985). In their calculation of indirect R&D acquired through domestic sources the OECD applied an input-output methodology, based on the so-called Leontief inverse (OECD 1994). This means that the indirect R&D from domestic sources for a particular industry in a particular country reflects not only the direct R&D carried out by its domestic suppliers but also the R&D acquired by these suppliers through their use of domestically produced capital goods and intermediates. For various reasons, indirect R&D acquired from foreign sources was calculated using a less sophisticated methodology, weighting direct R&D in the supplying (foreign) industries with actual import shares for the industry and country in question. As noted by the OECD this implies an underestimation of the total amount of foreign R&D. Probably, this does not constitute a serious problem in the present context, since the impact on the variables used here is likely to be small.[6]

Consistent with most theoretical perspectives in this area we expect a positive impact of both R&D and investment in physical capital (INV) on exports. Which of them is the most efficient way to enhance competitiveness is a matter of controversy. Some theories predict that the impact of investments in R&D (Romer 1990, Grossman and Helpman 1991) or physical capital (Romer 1986) is more prominent in large countries, we will be able to test for that as well. If there are important positive externalities stemming from use product-embodied R&D, we might expect a large positive impact of indirect R&D (DIF). An unresolved issue is as mentioned to what extent national boundaries matter for the impact of technology flows; the FOR variable was designed to throw some light on that. If the estimated impact is deemed to be not different from zero, this implies that the source (domestic or foreign) does not really matter. If on the other hand the estimated impact is negative, this means that indirect R&D from domestic sources is valued more highly, consistent with the suggestion from some theories in this area. Cost-competition figures

[6] To see this, recall that on average the share of domestic indirect R&D in total domestic R&D (direct and indirect) varies between one tenth and one fourth across OECD countries (Table 1). For the OECD as a whole this share is 20 %. Similarly, for the OECD as a whole, the share of foreign indirect R&D in total indirect R&D (DIF) is 23%. This means that on average the underestimation of DIF is (100*0.23*0.20)% = 4.6 % , not a very large number. Note also that in the case of the FOR-variable, foreign indirect R&D enters both in the numerator and the denominator, reducing the problem even further.

prominently in the public debate on competitiveness and in some theories as well (the product cycle theory, for example). To take this possibility into account we included the WAGE variable. We also included the HOME variable to allow for an impact of market size on competitiveness, consistent with some of the suggestions of "new trade theory" (the "home market effect"). Finally we test for the widely held view, often associated with the product cycle theory (Vernon 1966), that the impact of R&D and other factors vary systematically across broad classes of industry ('high-tech' versus 'medium' or 'low tech'). Following this theory R&D and market size should be of prime importance for competitiveness in innovative, high-tech industries, while in mature, low-tech industries investments in physical capital and low wages should be assumed to matter most.

A preview of the data

Table 1 gives summary statistics (total manufacturing) for the ten OECD countries included into the investigation for the year 1985.[7] There is a large spread in direct R&D efforts (as a percentage of production), with US far ahead of the others (3.5%). The remaining nine countries divide neatly in two groups, five in the area 2-2.5%, four between 0.7 and 1%. In the former we find Netherlands, Japan, France, UK and Germany, in the latter Italy, Australia, Canada and Denmark. As could be expected there is also a marked difference between large and small countries with respect to the importance of domestic versus foreign indirect R&D, with the large ones benefiting almost exclusively from the former and the small countries most geared towards the latter. This is clearly reflected in the share of foreign indirect R&D in total indirect R&D , column four in table 1 (the 'foreign share').

Table 2 ranks the 22 industries in our sample after their direct R&D intensity (calculated as direct business R&D divided by production[8]). More information about the definition of each of these industries is given in the appendix. If one adopts the criterion that an industry with R&D efforts 1.5 of the average or more is 'high tech', and one with efforts between 0.5 and 1.5 of the average 'medium tech', we end up with five high-tech industries (aerospace, computers, drugs, telecommunication/semiconductors and instruments) and five medium-tech industries (electrical machinery, other transport, cars, industrial chemicals and non-electrical machinery). The remaining 12 industries, many of which are related to use of natural resources in one way or another, are all 'low tech' by this definition.

[7] For the sake of exposition the variables have been deflated. The home market (domestic demand) is deflated by total OECD demand, wages by average OECD wages, the others are presented as share of production in the country in question. This affects this table only.

[8] A similar calculation was done with value added as deflator, the result was almost the same.

Results

The small sample (8-10 observations per industry, 17-20 observations per country) does not allow for very extensive testing of differences across industries and countries on the impact of the variables included in our investigation. What we do is to pool all the data and then test for the sensitivity of allowing the coefficients to vary across high, medium and low tech sectors and, where appropriate, also across countries of different sizes. All equations are estimated in logs by OLS. As part of the estimation procedure, tests for heteroscedasticity were conducted and heteroscedastic consistent standard errors (HCSEs) calculated (White 1980). The results indicate that heteroscedasticity is not an important problem in this case, e.g., the HCSEs did not differ much from standard errors as calculated by OLS. Hence, we report the latter.

It is common in analyses of this type to adjust for differences in size across countries and sectors. We do this by including a full set of country and industry dummies. What these do is to adjust for factors that affect competitiveness in the same way for each country (independent of industry) and industry (independent of country). These include size but also a host of other factors that impact on the propensity to export such as distance, transport costs etc. Thus, even if we had divided all variables by a measure of size such as, say, the labour force or GDP of the country, we would still have had to include dummies and, except for the dummies, the estimates thus obtained would have been identical to the ones reported here.[9]

Table 3 contain the main results from the estimations. Four different models are presented. The first (3.1) is our basic model (see equation 2). The three others extend the basic model by allowing for differences in the impact of variables across technology classes and country groups. In table 4 we test the different models against each other. Finally, we test for the sensitivity of changes in the specification and the way data are handled. Some of the more interesting results from these tests are included in table 5.

Generally, the results (equation 3.1) confirm many of our priors. Both direct R&D, indirect R&D and investment are positively correlated with competitiveness at the 1% level of significance. It is noteworthy that the estimated impact of indirect R&D is about twice as high as that of direct R&D. The foreign share had a significant negative impact, as suggested by several theories in this area. Contrary to popular belief, wage levels were found to be uncorrelated with competitiveness.[10] This confirms the finding from Wolff in this volume that low wages do not seem to be an important competitive factor among OECD countries. The size of the domestic market (HOME) has a

[9] An additional reason for including dummies in this case would be that the relation between the proprensity to trade and country size is clearly non-linear. For instance, large countries export much less compared to their size than small countries do.

[10] The wage level is sometimes used as a proxy for skills, thus one might perhaps have expected a high correlation with direct R&D efforts. However, the result that WAGE is uncorrelated with exports holds even when direct R&D is excluded (not reported).

significant negative impact, in contrast to the predictions of some theories emphasising economies of scale.

When the impact of the variables were allowed to vary across high, medium and low tech sectors (equation 3.2) the explanatory power of the model increased somewhat. The test (Table 4) suggest that this is a real improvement, indicating that there are important differences across sectors in the way variables work. The impact of direct R&D, for example, is about twice as large in high-tech as in low-tech industries. Indirect R&D and investment in physical capital, on the other hand, appear to matter more in low tech. To some extent these results resemble the kind of 'stylised' facts that led Vernon (1966) to formulate the product cycle theory. However, low wages do not seem to matter, not even in low tech, where cost-competition – following Vernon – should be expected to have a sizeable impact. Following Vernon one might also have expected market size to be positively correlated with competitiveness in high tech. The results suggest that competitiveness is negatively correlated with market size in all three sectors, but less so in high tech than in the other sectors.

A division of countries into large, medium-sized and small can be made along the same lines as for the technology-classes. If this methodology is adopted, two countries appear as large; USA and Japan. The medium-sized countries are Italy, UK, France and Germany. The difference in economic size between these countries and the remaining ones, which all are small by this definition, is also evident from Table 1. According to new growth theory, the rewards from investments in R&D and/or physical capital should be larger in large countries. We test for this by allowing the estimated impact of R&D and investment in large and medium-sized countries to deviate from the rest of the sample, i.e., the small countries (equation 3.3.). For physical capital there is little evidence of large-country advantages. If anything it is the other way around. However, there is strong support for the hypothesis that direct R&D has a higher impact on exports in large countries. Furthermore, the test in Table 4 also suggests that the version allowing for large-country advantages (3.3) should be preferred when tested against the basic model (3.1).

What is the interpretation of this? That large countries specialise in high tech industry is no secret. Apparently they also get more out of their investments in R&D. However, do they specialise in high tech because they get higher rewards to R&D, or do they enjoy higher rewards because they specialise in high tech? Unfortunately we are unable to tell. As is evident from Tables 3-4, if we start out with one of these assumptions (sector or size differences), then adding the other does not increase the explanatory power of the model in a significant way. This might perhaps have been different for a larger sample of countries including, for instance, some small high-tech countries such as Sweden and Switzerland. For the present sample, however, sector and size differences go hand in hand.

Some of the implications of these results might be clearer by way of an example. Assume that we want to know the impact on exports of reallocating a part, say 1 %, of a country's investments in physical capital to direct R&D. Since on average the OECD countries invest twice as much in physical capital as in R&D, this means that an average country would have to increase direct R&D with 2 %. Our basic model (3.1.), which we will use here, estimates that a 1% reduction in investment in physical capital reduces exports by - 0.69 %, while a 2 % increase in indirect R%D increases it by 0.36 %, indicating a net loss in exports of -0.33 % from this operation. For the economy as a whole, however, this may be different, because a general increase in direct R&D also implies a rise in the R&D content of the goods and services that firms acquire from their domestic suppliers. For simplicity we abstract from any change that might occur in the demand or price level of domestic inputs as a result of the reallocation from investment in physical capital to R&D. Furthermore, let us assume - as seems reasonable - that the ratio between direct and indirect R&D is constant, so that a 2 % increase in direct R&D implies a 2 % increase in the domestic part of the total indirect R%D. On these assumptions (and based on the estimates in 3.1.) the impact on exports of increased domestic indirect R&D, caused by a 2% increase in direct R&D, can be calculated to 0.87 %.[11] This indirect gain more than outweighs the direct loss, indicating a net gain of 0.54 % for the country as a whole. Thus, for the average country, R&D appears to be a more potent competitive factor than investments in physical capital. For the individual firm, however, this may not be so clear, because the lion's share of this effect accrues to other domestic firms. This resembles the familiar case from the literature, where a large gap between social and private rectums to R&D justifies a R&D subsidy.

This example may also be applied to countries of different sizes. It then becomes clear that the basic model generates some unwarranted results. Since small countries do much less R&D compared to what they invest than large countries, an increase in R&D equivalent to 1% of investment translates itself to a much bigger per cent increase in direct R&D in a small country than in a large one. If, as in the basic model, the impact of direct R&D on exports is assumed to be the same across industries and countries, this implies that this effect is much larger in small countries than in large ones. In fact, for an average small country - using the estimates in 3.1. - an increase in direct R&D equivalent to 1% of investment leads to a 0.83 % increase in exports compared to only 0.32 % for an average large country. If this was the case, then firms in small countries should face a stronger (private) incentive to invest in R&D than firms in large countries. This is, of course, contrary to what we observe. Allowing for differential impact of investment in R&D and physical capital across technology classes or countries of different size adjusts for this. For instance, when large-country advantages are allowed (3.3), an increase in direct R&D equivalent to 1 % of investment yields 0.59% increase in exports in a small country compared to 0.92 % for a large one, consistent with

[11] The formula used for calculating the total indirect effect (including the decrease in the foreign share) is b(1-f)(0.37) + (-b(1-f)(-0.25)) where b is the increase in direct R&D (0.02) and f the foreign share (0.23).

observation that firms in small countries devote much less resources to R &D than firms in large countries. The total (combined direct and indirect) effect is also stronger in large countries than in small ones if large-country advantages are allowed. However, the conclusion of the previous paragraph,i.e., that the total impact on exports of an investment of given size is larger for R&D than for physical capital, still holds for all countries (independent of size).

We are not aware of any study that may be directly compared to this one. There are, however, some attempts to quantify the impacts of direct and indirect R&D on productivity, see in particular the recent study by Coe and Helpman (1995). Arguably, for a sample of high-income countries, competitive advantages and superior productivity should be expected to go hand in hand,[12] so perhaps something may be learned by comparing their results to ours. What they find, based on evidence for OECD countries in the last decades, is that the returns to R&D investments are high, especially in the larger and medium-sized countries. This is in accordance with the findings reported here. Furthermore, they report that for the larger countries, domestic R&D matters most, while for the small countries R&D acquired indirectly through imports is the most important source of technological advance. To see how this latter finding compares to the results of this study, assume a 1 % increase in R&D world-wide that leads to a similar increase in indirect R&D (this leaves the ratio between foreign and domestic indirect R&D unaffected). Using the estimates in 3.3. (allowing for large-country advantages) the combined direct and indirect impact on exports from domestic sources can be shown to be 0.21% for the small , 0.39 % for the medium-sized and 0.85 % for the large countries. Similar estimates for the foreign contribution are 0.29 % for the small, 0,14 % for the medium-sized and 0.04% for the large countries. Hence, for the largest countries inflows of technology through trade are of negligible importance compared to technology from domestic sources, while for the small countries the foreign contribution is what matters most. Thus, our results, although based on different data and methods, are consistent with those reported by Coe and Helpman.

How sensitive are the results reported here for changes in specification? We tested this extensively, and the results appear reasonably robust. The two first columns in Table 5 (5.1-2) report the result from substituting the dependent variable (log exports) with the log of the export-import ratio, a measure of export specialisation. The results were only marginally different from those reported in Table 3 apart from, perhaps, that the detrimental impact of relying heavily on technology import (the foreign share) was even more pronounced. In the two next columns (5.3-4) we report the result of deflating all level variables (all variables except “foreign share”) with the number of workers in the industry and country in question. This implies a slight change in the meaning of the test, since this way of doing things excludes that part of the total variance which refers to cross-country differences in the employment

[12] See the discussion and empirical evidence in Wolff and Gustavsson et al. in this volume.

structure.[13] Still, the results were not qualitatively different, although the numerical values of the estimates were lower in most cases. We also checked for the impact of excluding the HOME variable, since the estimated impact of this variable, although highly significant, was contrary to expectations. Again the numerical estimates were lower, but not qualitatively different. Finally we made an attempt to include a variable reflecting "human capital" (RSE), defined as (the log of) the share of researchers, scientists and engineers in the labour force of the industry and country in question (source: OECD), even if this implied a marked reduction in the size of the sample (5.5). However, the RSE variable turned out to be uncorrelated with competitiveness.[14]

Concluding Remarks

The purpose of this study has been to explore the relation between competitiveness, scale and R&D with the help of OECD Data Bases and the ongoing work in the OECD on embodied technology flows. The results suggest that both direct and indirect R&D have a significant, positive impact on competitiveness. Indirect R&D from domestic sources appear to be more conducive to competitiveness than indirect R&D from abroad. On average the total (direct and indirect) impact of a given investment in R&D on exports is about twice as large as the impact of an investment of similar size in physical capital. The impact of R&D investment appears to be especially high in large countries and R&D intensive industries.

However, the preliminary and exploratory character of the study should be stressed. What is presented here is a pure cross-sectional analysis. As is well known this does not allow for testing of causality. The most we can do is to use our theoretical knowledge as a guide for presenting and analysing the structure (and relationships) of the data and compare the findings thus obtained with the theoretical predictions. Furthermore, the number of countries included is small, and this may bias the results, in particular since many of the omitted countries are small countries. Finally, although these data go much further than most other data sets in quantifying knowledge flows, disembodied knowledge flows are clearly not accounted for. Further research and more extensive data are necessary to validate these results and to dig deeper into the question of how scale, R&D and other factors interact in the competitive process.

[13] The industrial composition of the labour force reflects the pattern of specialization. By using this as deflator we remove that part of the total variance which refers to differences in specialization patterns.

[14] This might be due to multicollinearity with the direct R&D and/or wage variabels. However, even when these variables were excluded (not reported), the RSE variable failed to make a significant impact.

References

Amable, B. and B. Verspagen (1995) The role of technology in market shares dynamics, *Applied Economics* 27: 197-204

Amendola g, G Dosi and E. Papagni (1993) The Dynamics of International Competitiveness, *Weltwirtschaftliches Archiv* 129: 451-471

Coe, D.T. and E. Helpman (1995) International R&D Spillovers, *European Economic Review* 39: 859-887

Dosi, G. and L. Soete (1983) Technology Gaps and Cost-based Adjustment: Some Explorations of the Determinants of International Competitiveness, *Metroeconomica*. 35: 357-382

Dosi, G., K. Pavitt, H. and L. Soete (1990) *The Economics of Technical Change and International Trade*, Harvester Wheatsheaf, London.

Dosi, G. and L. Soete (1988) Technical change and international trade, in Dosi, G. et al. (eds) *Technical Change and Economic Theory*, Pinter, London

Fagerberg, J. (1988) International Competitiveness, *Economic Journal* 98: 355-374

Fagerberg, J. (1995a) *Is there a large-country advantage in hightech?* Working Paper No. 526, January, Norwegian Institute of International Affairs, Oslo

Fagerberg, J (1995b) User-Producer Interaction, Learning and Comparative Advantage, *Cambridge Journal of Economics* 19: 243-256

Greenhalgh, C. (1990) Innovation and Trade Performance in the United Kingdom, *Economic Journal* 100 (Conference 1990): 105-118

Greenhalgh, C., P. Taylor and R. Wilson (1994) Innovation and Export Volumes and Prices – A Disaggregated Study, *Oxford Economic Papers* 46: 102-134

Grossman, G.M. and E. Helpman (1991) *Innovation and Growth in the Global Economy*, Cambridge(USA): The MIT Press

Grossman, G.M. and E. Helpman (1995) *Technology and Trade*, Discussion Paper Series No. 1134, February, CEPR, London

Helpman, E. (1984) Increasing Returns, Imperfect Markets and Trade Theory, in Jones, R.W and P.B. Kenen: *Handbook of International Economics, Volume 1*, North-Holland, Amsterdam

Krugman, P. (1990) Rethinking International Trade, Cambridge(USA): The MIT Press

Lacroix, R. and P. Scheuer (1976) L'Effort de R&D, l'Innovation et le Commerce International, *Revue Economique*, no. 6, pp. 1008-1029

Lundvall, B. Å. (1985) *Product Innovation and User-Producer Interaction*, Aalborg University Press, Aalborg

Lundvall, B. Å. (1988) Innovation as an Interactive Process – from User-Producer Interaction to the National System of Innovation, in Dosi, G. et al. (eds) *Technical Change and Economic Theory*, Pinter, London

Lundvall, B.Å. (ed) (1992) *National Systems of Innovation – Towards a Theory of Innovation and Interactive Learning*, London: Pinter

Magnier, A. and J. Toujas-Bernate (1994) Technology and Trade: Empirical Evidence from Five Industrialized Countries, *Weltwirtschaftliches Archiv* 130: 494-420

Nelson, R. (ed.) (1993) *National Innovation Systems, a Comparative Study*, Oxford: Oxford University Press

OECD (1994) *Technology Diffusion Flows in 10 OECD Countries*, DSTI/IND/STP/ICCP(94)8

Porter, M. E. (1990) *The Competitive Advantage of Nations,* MacMillan, London

Posner, M. V. (1961) International Trade and and Technical Change, *Oxford Economic Papers* 13: 323-341

Romer, P.M. (1986) Increasing Returns and Long-Run Growth, *Journal of Political Economy*. 94: 1002-1037

Romer, P.M. (1990) Endogenous Technological Change, *Journal of Political Economy* 98: S71-102

Soete, L. (1981) A General Test of Technological Gap Trade Theory, *Weltwirtschaftliches Arkiv* 117: 638-660

Soete, L.(1987) The Impact of Technological Innovation on International Trade Patterns: The Evidence Reconsidered, *Research Policy* 16:. 101-130

Venables, A. (1994) Economic Integration and Industrial Agglomeration, *The Economic and Social Review* 26: 1-17

Vernon, R.(1966) International Investment and International Trade in the Product Cycle, *Quarterly Journal of Economics* 80: 190-207

Walker, W. B. (1979) Industrial Innovation and International Trading Performance, Greenwich: JAI Press

White, H. (1980) A heteroskedastic-consistent covariance matrix estimator and a direct test for heteroskedasticiy, *Econometrica*. 48: 817-838

Table 1. Summary statistics - 10 OECD countries, 1985

	Direct R&D	Domestic indirect R&D	Foreign indirect R&D	Foreign share	Relative wage level	Market size	Investment share
USA	3.5	0.8	0.1	11.1	146.5	39.8	3.9
Netherlands	2.0	0.2	0.7	77.8	107.1	1.7	5.8
Japan	2.0	0.7	0.1	12.5	73.3	20.2	6.3
Italy	0.7	0.2	0.2	50.0	87.7	7.4	5.5
UK	2.2	0.3	0.4	57.1	94.2	7.4	4.1
France	2.0	0.4	0.3	42.9	106.9	7.1	5.0
Denmark	1.0	0.1	0.4	80.0	74.5	0.6	5.6
Germany	2.5	0.6	0.2	25.0	102.7	11.0	4.1
Canada	1.0	0.2	0.6	75.0	117.3	3.3	4.5
Australia	0.9	0.3	0.3	50.0	89.8	1.6	5.2

Table 2. R&D intensity, production, 1985

High		Medium		Low	
Aerospace	20.08	Elec. mach.	3.26	Stone, glass	1.10
Computers	10.41	Other transp.	3.03	Plastics	1.01
Drugs	9.01	Cars	2.83	Non-fer. met.	0.89
Telecom.	7.88	Ind. chem.	2.76	Petroleum ref.	0.78
Instruments	6.10	Nonelec. mach.	1.68	Fabr. met. pr.	0.64
				Other manufac.	0.64
				Ferr. met.	0.61
				Ships	0.36
				Food, drinks	0.29
				Paper	0.23
				Textiles	0.19
				Wood, furnit.	0.16

High: R&D intensity 1.5 times the mean R&D intensity or higher
Low: R&D intensity 0.5 times the mean R&D intensity or lower
Medium: R&D intensity between 0.5 and 1.5 times the mean R&D intensity

Table 3. Factors affecting exports, 1985

Equation	3.1	3.2			3.3	3.4		
		High tech	Medium tech	Low tech		High tech	Medium tech	Low tech
Direct R&D	0.18 (2.76) *	0.52 (3.22) *	0.15 (1.00)	0.18 (2.45) **	0.12 (1.63) ***	0.47 (2.52) **	0.14 (0.87)	0.17 (1.87) ***
Indirect R&D	0.37 (3.24) *	0.32 (1.81) ***	0.59 (2.05) **	0.52 (2.99) *	0.44 (3.79) *	0.33 (1.87) ***	0.69 (2.32) **	0.53 (2.93) *
Foreign share	-0.25 (2.14) **	-0.56 (2.25) **	-0.24 (1.11)	-0.26 (1.96) ***	-0.34 (2.86) *	-0.45 (1.70) ***	-0.10 (0.44)	-0.32 (2.34) **
Invest ment	0.69 (6.63) *	0.34 (1.43) ****	0.51 (2.04) **	0.68 (5.28) *	0.67 (5.54) *	0.36 (1.41) ****	0.48 (1.83) ***	0.73 (4.76) *
Wage	0.06 (0.18)	-0.09 (0.42)	0.47 (0.89)	-0.05 (0.16)	-0.00 (0.01)	-0.20 (0.46)	0.24 (0.45)	0.32 (0.08)
Home market	-0.51 (2.87) *	-0.51 (1.79) ***	-0.41 (1.35) ****	-0.85 (3.77) *	-0.64 (3.66) *	-0.56 (1.91) ***	-0.46 (1.46) ****	-0.93 (3.97) *
R&D-large	–		–		0.44 (3.90) *		0.24 (1.37) ****	
R&D-medium	–		–		0.09 (1.42) ****		-0.01 (0.15)	
Investment-large	–		–		-0.21 (1.28)		-0.06 (0.30)	
Investment- medium	–		–		-0.15 (1.26)		-0.09 (0.69)	
Country dummies	yes		yes		yes		yes	
Product dummies	yes		yes		yes		yes	
$\bar{R}^2$ (R^2)	0.86 (0.83)		0.89 (0.85)		0.88 (0.85)		0.89 (0.85)	

Notes:
Estimated in log-form. For definition of variables, see text. N=192.
Absolute t-statistics in brackets.

*, **, ***, **** = Significant at 1%, 5%, 10%, 20% level, respectively

Table 4. Testing for inclusion of additional variables

Country and product dummies	3.1 (against 3.0 [1])	$F_{(28,157)} = 10.03$ (*)
High, medium and low R&D Sectors	3.2 (against 3.1)	$F_{(12,145)} = 2.59$ (*)
Large-country advantages (R&D and Investment)	3.3 (against 3.1)	$F_{(4,153)} = 4.86$ (*)
	3.4 (against 3.2)	$F_{(4,141)} = 1.28$
	3.4 (against 3.3)	$F_{(12,141)} = 1.37$

Notes
1) 3.1 without country and product dummies (a common constant term),

$R^2 = 0.61$, not reported.

* Significanse of test, 1% level.
** Significanse of test, 5% level.
*** Significanse of test, 10% level.

Table 5. Testing for changes in specification

Equation	5.1	5.2	5.3[1)]	5.4[1)]	5.5	5.6
Dependent variable:	Export - import ratio	Export - import ratio	Exports per worker	Exports per worker	Exports	Exports
Direct R&D	0.22 (2.62) *	0.14 (1.55) ***	0.20 (2.92) *	0.12 (1.60) ****	0.17 (2.54) *	0.19 (1.48) ****
Indirect R&D	0.37 (2.59) *	0.48 (3.35) *	0.29 (2.44) **	0.32 (2.66) *	0.25 (2.33) **	0.37 (2.45) **
Foreign share	-0.62 (4.16) *	-0.70 (4.85) *	-0.18 (1.52) ****	-0.25 (2.03) **	-0.23 (1.93) ***	-0.32 (2.31) **
Investment	0.85 (6.49) *	0.79 (5.33) *	0.50 (4.01) *	0.65 (4.16) *	0.59 (5.88) *	0.74 (5.25) *
Wage	0.33 (0.80)	0.27 (0.69)	0.29 (0.82)	0.26 (0.74)	0.02 (0.06)	0.02 (0.06)
Home market	-0.84 (3.77) *	-1.07 (4.96) *	-0.43 (3.01) *	-0.31 (2.02) **	–	-0.70 (3.11) *
RSE (Human capital)	–	–	–	–	–	-0.00 (0.03)
R&D-large	–	0.56 (4.09) *	–	0.38 (3.35) *	–	–
R&D-medium	–	0.11 (1.39) ****	–	0.09 (1.31) ****	–	–
Investment-large	–	-0.07 (0.34)	–	-0.66 (2.87) *	–	–
Investment-medium	–	-0.17 (1.15)	–	-0.37 (2.06) **	–	–
Country dummies	yes	yes	yes	yes	yes	yes
Product dummies	yes	yes	yes	yes	yes	yes
$\bar{R}^2$ (R^2)	0.62 (0.53)	0.68 (0.60)	0.80 (0.76)	0.82 (0.77)	0.86 (0.82)	0.86 (0.82)
N	192	192	192	192	192	152

Notes
Estimated in log-form. For definition of variables, see text.
Absolute t-statistics in brackets.
* = Significant, 1% level
** = Significant, 5% level
*** = Significant, 10% level
**** = Significant, 20 % level

1) In this equation, all variables except "foreign share" are divided by the number of workers in the industry and country in question.

Appendix: STAN Classification

ISIC codes	Names
3100	Food, drink & tobacco
3200	Textiles, footwear & leather
3300	Wood, cork & furniture
3400	Paper & printing
351+352-3522	Industrial chemicals
3522	Pharmaceuticals
353+354	Petroleum refining
355+356	Rubber & plastics products
3600	Stone, clay & glass
3710	Ferrous metals
3720	Non-ferrous metals
3810	Fabricated metal products
382-3825	Non-electrical machinery
3825	Office machinery & computers
383-3832	Electrical machinery
3832	Electronic equipment & components
3841	Shipbuilding
3842+3844+3849	Oth transport equipment
3843	Motor vehicles
3845	Aerospace
3850	Instruments
3900	Other manufacturing
30000	Total manufacturing