

EPRU Working Paper Series

**Economic Policy Research Unit
Institute of Economics
University of Copenhagen
Studiestræde 6
DK-1455 Copenhagen K
DENMARK
Tel: (+45) 3532 4411
Fax: (+45) 3532 4444
Web: <http://www.econ.ku.dk/epru/>**

Technological Revolutions, Innovations, and Trade Performance

Jakob B. Madsen

2004-12

ISSN 0908-7745

**The activities of EPRU are financed by a grant from
The National Research Foundation**

Technological Revolutions, Innovations, and Trade Performance¹

Jakob B Madsen
Institute of Economics and EPRU
University of Copenhagen

Abstract. This paper addresses two puzzles in international trade, namely why traditional estimates of income elasticities of exports are implausibly high and why the export growth varies much more markedly across countries than can be explained by price competitiveness and variations in income in export markets. Using data for 18 OECD countries it is shown that integration, the level of technology and the technological competitive position can, to a large degree, explain these two puzzles.

JEL Classification: F10, O30.

Key Words: Technology, external patents, product variety, trade, ICT revolution.

1 Introduction

The invention in 1971 of the microprocessor by Intel was the beginning of what developed into the new technological revolution in the 1990s that is often referred to the information and communication technological (ICT) revolution (Jovanovic and Rousseau, 2003). The surge in innovative activity in the 1990s is signified by the fact that from 1991 to 2001 the total number of patent applications for increased three times as much as they did from 1981 to 1991.²

OECD exports also surged in the 1990s. Real exports of goods and services grew by three times the GDP growth over the period from 1993 to 2000 (OECD Economic Outlook, 2004), which either suggests implausibly high income elasticities in foreign trade, effects of the increasing globalisation, the ICT revolution, or increasing technological innovations in general. Economists have long been puzzled by the high and varying income elasticities found in foreign trade across countries and argue that much more important forces than price competitiveness, such as product variety and technology, are at work (Kaldor, 1978, Krugman, 1989, Fagerberg, 1996). A further puzzle is the cross-country diversity in the growth in real manufacturing exports. Again the 1990s stands out. Whereas Japan experienced a 14% increase in real manufacturing exports from 1991 to

¹ Support from an EPRU grant from the Danish government is gratefully acknowledged. Signe Skarqvist and Randall Fox provided excellent research assistance.

2001, Ireland witnessed a 160% increase over the same period without experiencing an improvement in price competitiveness. Clearly, traditional trade models, where trade is a function of income and price competitiveness, fail to explain these facts.

These puzzles have attracted much attention in the theoretical literature. Krugman (1980, 1989) and Helpman (1990) show that trade is, to a large extent, an outcome of product variety and argue that some countries have higher income elasticities in exports than other countries because they expand the range of products they produce. The models of Krugman (1983), Spencer and Brander (1983) and Grossman and Shapiro (1987), furthermore, establish a theoretical link between international technological competitiveness and international trade. These models, therefore, suggest that technology and product variety influence the level of trade as well as the relative performance among nations.

Using long historical data for the OECD countries this paper examines the influence on exports of the *level* and *competitiveness* of technological and product variety. More specifically, the paper investigates 1) the ability of the *level* of technology and product variety to explain manufacturing exports over time and across countries; 2) the effects on exports of technological and product variety *competitiveness*; 3) the sensitivity of income elasticities of exports to the inclusion of technology, product variety and integration; and, most importantly, 4) the effects on exports of patents applied for by domestic producers in their export markets. Technology and product variety are measured as the stock of business R&D financed by business, the stock of patents, the stock of model designs, and the stock of trade marks. Patents and R&D are not treated as substitutes, but as complements, because they measure different aspects of technology and product variety.³ Patents are an outcome of formal and informal R&D activity and, as such, have a broader coverage than R&D expenditures. R&D, by contrast, gives more weight to important innovations, whereas every patent counts the same regardless of the significance of the innovation. That R&D stock and patent stock are considered here as complements is consistent with the fact that they are only weakly correlated over time, as shown in Section 3.

Whereas a number of studies have examined the effects on trade and particularly on market shares of technological competitiveness, hardly any work has been done in 1) investigating the export effects of patents applied for by domestic producers on their export markets; 2) addressing the income elasticity puzzle; 3) examining the effects on exports of the stock of

² The data period ends in 2001 in this study because the patent data have a publication lag of approximately 3½ years.

³ Fagerberg (1988) also uses both patents and R&D. His technological competitiveness index is based on the average of patents and R&D, weighted by their relative variances.

technology and product variety; and 4) scrutinizing the effects of the explosion technology on trade in the 1990.

In his seminal paper Fagerberg (1988) found that technological competitiveness, measured by relative aggregated R&D expenditures and patents, had important effects on aggregate exports for the OECD countries, and that the increasing Japanese technological competitiveness accounted for a significant part of its export success over the period from the mid 1960s to the mid 1970s. Similar effects have been found by Amable and Verspagen (1995), Amendola *et al.* (1993) and Magnier and Toujas-Bernate (1994) using pooled cross-section and time-series analysis for the OECD countries. Based on sectoral data a number of empirical studies have examined the effects on trade and market shares of technological and product variety competitiveness on sectoral market shares and trade in the contributions by Anderton (1999), Carlin *et al.* (2001), Fagerberg (1997), Greenhalgh (1990), Greenhalgh *et al.* (1994), and Magnier and Toujas-Bernate (1994).⁴

The inclusion of external patents in this study is potentially very important for the understanding of the path in market shares over time. Domestic patents do not give protection against imitators producing or selling in the export markets beyond the first year after the patent application is filed (OECD, 2001). Exporters, therefore, have strong incentives to protect innovations that have 1) commercial promise in their export markets, and 2) that still have commercial promise one year after filing for a patent (OECD, 2001). A priori we would, therefore, expect that external patents to be much more influential for exports than patents applied for domestically. Furthermore, external patents accounted for 83% of all patent applications in 2001 in the countries considered in this study, which underlines their potential importance for studies of the effects on exports of technology and product variety.

The importance of external patents has increased substantially in the post-war period and particularly in the 1990s. The increasing importance of external patents in the 1990s is signified by an almost 400% increase in external patents applied from 1991 to 2000 for the 18 countries considered in this study. In comparison, domestic patents applied for increased by less than 50% over the same period. Furthermore, whereas external patent applications by Irish residents increased by 565% over the period from 1991 to 2001, they increased by less than a half of this magnitude in the majority of other OECD countries over the same period.⁵ External patenting may, therefore,

⁴ For surveys of the literature see Fagerberg (1996) and Dosi *et al.* (1990).

⁵ The year 2000 is used as the final year for external patents attributed to the residence of applicant because of an almost four-year publication lag. By contrast external patents distributed by host country only has a publication lag of almost three years.

hold the key to the explanation of the surge in exports in the 1990s and its large cross-country variation.

Despite their potential importance no empirical studies have, to my knowledge, used external patent stocks in models of exports, which probably reflects the enormous difficulties that are associated with the data collection because foreign patent applications for each individual host country need to be distributed by country of residence of the applicant. The patents applied for abroad by US residents, for instance, are only recorded by the patent offices in the host countries. Thus data sources for each individual country in the OECD are needed. Although the WIPO has recently started to collect these data, national sources are required to give a sufficiently long sample period and for the computation of knowledge stock data.

Two other distinguishing features of this paper are that 1) *stock* as opposed to *flow* data on technology and product variety are used; and that 2) a multilateral competitiveness index for the stock of technology and product variety is used. Stock as opposed to the flow of technology and product variety is the relevant measure of export potential because the stock of technological knowledge is constantly depreciating. Since, technological knowledge stock and the marketability of a product depreciates rapidly, the innovative activity needs to be kept up at a certain level to maintain a constant stock of knowledge and product variety without experiencing a decline in exports *ceteris paribus*.

Technological and product variety competitiveness are traditionally measured as R&D expenditure or patents relative to the major countries or all OECD countries; thus implicitly assuming that countries face the same competitors. This is a highly restrictive assumption. Despite being the key variable in studies of the influence of technology and product variety on exports, it is surprising how little discussion there has been in the literature of the construction of the competitiveness index. This paper uses a new method to construct an index of the technological competitive position that weights competitors according to their market shares in export markets, including the market share of domestic producers. This index acknowledges the fact that exporters compete with third country exporters as well as domestic producers in the export markets. The approach is closely related to the method used by the OECD and the IMF to construct price competitiveness indexes.

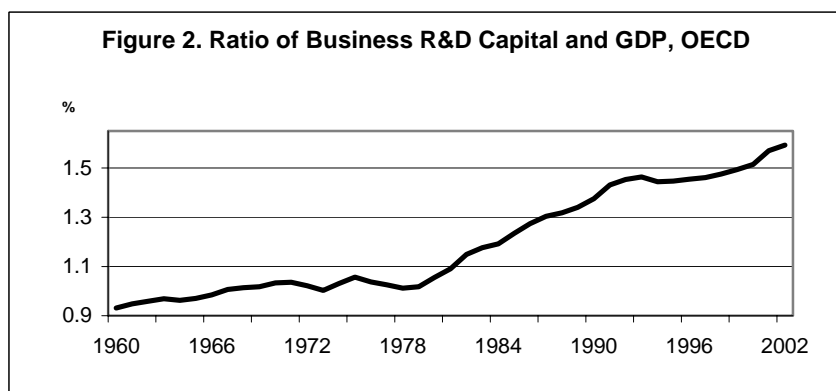
2 Trade, technology and product variety

Before turning to the econometric estimates in Section 4, this section offers time series evidence on manufacturing exports, technology and product variety. Data construction is discussed in Section 3. Non-manufacturing merchandise trade is not considered because its supply and demand is heavily influenced by weather, embargos and discoveries of new mining fields and little influenced by relative prices, demand, product variety and technology.



Notes. The following 18 countries are included in the figure: Canada, the US, Japan, Australia, Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the UK. The ratio is a weighted average of GDP at purchasing power parities.

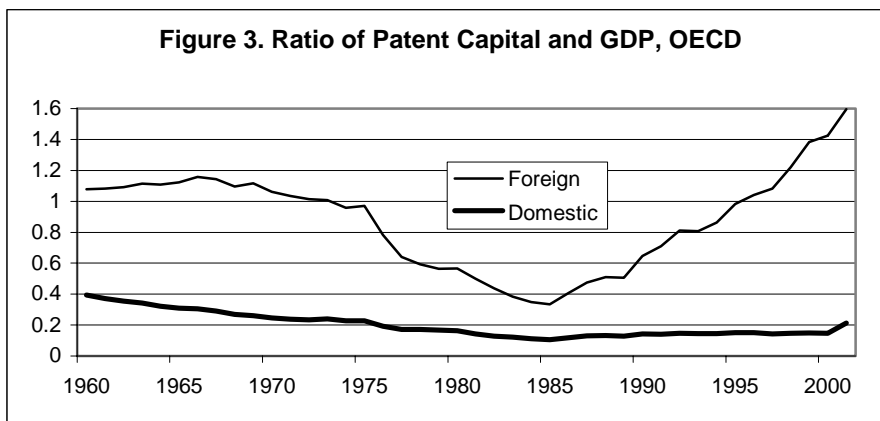
Figure 1 shows the ratio of the weighted average of real exports of manufacturing products to real GDP for the 18 OECD countries that are used throughout this study. Real GDP at purchasing power parity is used as weights. The ratio is fluctuating about an increasing trend over the whole period, which suggests that income elasticities in foreign trade are either greater than one or factors other than income, such as the range of differentiated products and new technologies, have contributed to the growth in world trade.



Note: See notes to Figure 1.

The period from 1993 to 2000 stands out as a period in which the trade in manufacturing products increased markedly and signifies a break in the trend, and is of particular interest since it coincides with the ICT revolution and a surge in the innovative activity in general (OECD, 2003, Jovanovic and Rousseau, 2003). Another revealing feature of the figure is that the fluctuations of the export-income ratio are pro-cyclical, which suggests that exports are not only a function of the level of income but also the growth in income; a feature that is supported by the empirical estimates in Section 4.

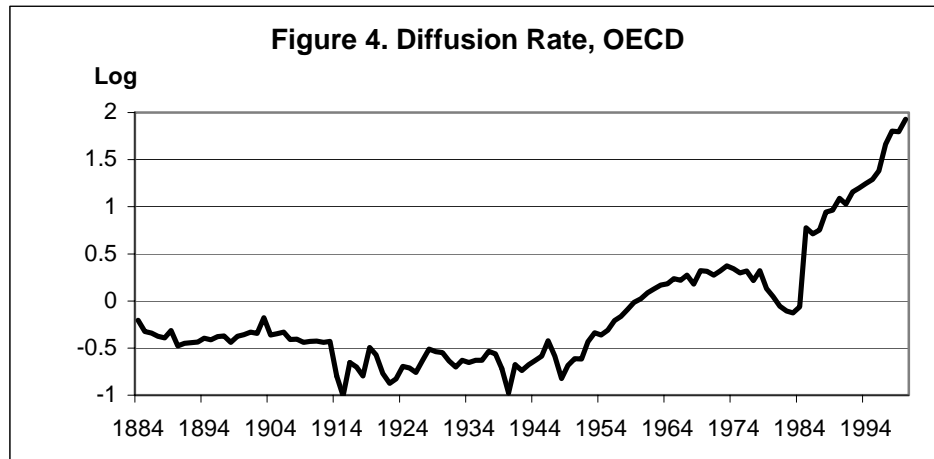
Figure 2 displays a weighted average of the ratio of *real* private business financed R&D stock to *real* income. Private sector R&D expenditures as opposed to total R&D expenditures are used because private R&D expenditures are directed toward commercial inventions and imitations. One should, therefore, expect exports to be more influenced by business R&D than government financed R&D. The curve shows an almost constant ratio of R&D capital and income up to 1980, a significant rise over the period from 1980 to 1993, and thereafter only a slight increase. This path is not compatible with the path in the export-income ratio; particularly not in the 1990s where the strong increase in OECD exports was not followed by increasing ratio of R&D stock and income.



Note: See notes to Figure 1.

Figure 3 displays the path of the ratio of patent stock and real GDP in USD, where the patent stock is divided into domestic and external patents. The construction of the patent stock is addressed in the next section. Patents granted have not been used because of the long and varying time-lag between the innovation and the granting of the patent (Griliches, 1990, OECD, 2001). Comparing the figures for patent stock and R&D stock indicates diminishing returns to R&D up to 1993; a

feature that has been intensively discussed in the literature (see for instance Griliches, 1990, and Nadiri, 1993). The post-1993 surge in the ratio of the external patent capital stock and GDP is consistent with the marked increase in the trade-income ratio in the same period, which raises the possibility that the external patenting activity has played a major role in the OECD trade expansion over the period from 1993 to 2000.



Note: See notes to Figure 1.

To get a long historical perspective on the relative importance of the propensity of producers to patent on export markets relative to the domestic market, the diffusion rate is displayed in Figure 4, where the diffusion rate is defined as the ratio of external patents at period t and domestic patents at period $t-1$ (OECD, 1990). This measure shows the spread of technological innovations and new products externally of domestic producers on export markets and thus the export potential and globalisation of the world economy.

The figure identifies globalisation waves over the period from 1945 to 1974 and particularly over the period from 1985 to 2000. Both periods are characterised by strong increases in exports, particularly in the *post* 1985 period; thus raising the possibility that patenting abroad has been influential for the expansion in world trade in the 1960s and particularly in the 1990s. Exporting firms' external patenting has the potential to enhance exports because it enhances the product variety in foreign markets, but at the same time crowds out, in the export market, the sales of domestic and third country producers. These effects are distinguished in the Section 4.

3. Measurement and data issues

Five different stock and competitiveness measures of technology and product variety are used, namely, patents applied for by domestic applicants, real business R&D expenditures financed by business, trade marks applied for, product designs applied for, and patents applied for abroad. Their relative merits and their construction are discussed in this section.

3.1 Indicators of technology and product variety

As widely acknowledged in the literature, patent counts and R&D, although imperfect, are probably the best available measures of product variety and technology. The relative merits of patents and R&D have been discussed extensively elsewhere (see for instance Greenhalgh *et al.*, 1994, Griliches, 1990, and Nadiri, 1993). Therefore, the discussion of this issue here will be brief. Patents benefit from *not* being measured with an error and are outcomes of informal as well as formal R&D activities. However, more important innovations will be more R&D intensive and will, consequently, be reflected better in the R&D stock, whereas innovations have the same counts in patent regardless of their significance. Furthermore, a large proportion of R&D expenditure may be devoted to development and inventions that are not patentable, industries with significant support from government tend to have a low patenting propensity, and not all inventions are of a patentable nature (Nadiri, 1993). These considerations suggest that R&D and patents are potentially excellent complements.

Correlation coefficients between patents and R&D give some insight into the complementarity issue. The correlation coefficient between the log differences in patent stock of domestic applications and the business R&D stock is 0.08 for the 18 OECD countries considered here over the period from 1966 to 2001. The corresponding figure for R&D and patent stock competitiveness is 0.03. Based on sectoral data Greenhalgh *et al.* (1994) reach the same results. Interestingly, the correlation coefficient between the log differences in the patent stock of external applications and the log differences in the business R&D stock is 0.22, which suggests that a significant fraction of business R&D is directed towards new products that are sold in export markets. This result is reinforced by a corresponding figure for competitiveness of 0.18.

External patents are potentially more important for exports than patents taken domestically because a domestic patent does not give world-wide protection beyond one year after the application is filed, as discussed above. Exporting firms, therefore, have large incentives to patent their most important inventions in their most important export markets. A patent in any

specific country provides 1) protection from imitation in the specific market; and 2) protects the inventor from outside imitators selling in that country (OECD, 2001). Since external patenting is expensive only the most commercially valuable inventions are patented abroad (Eaton and Kortum, 1996). Consequently, external patents are likely to contain much more information about export potential than domestic patents and R&D.

New product designs and trade marks rarely embody new technologies, and as such are cleaner measures of product variety than patents and R&D. One may, however, question their usefulness in identifying new product varieties because only a few new products presumably require a design patent or are created from new trade marks. Trade marks and product design patents are, therefore, incomplete proxies of product varieties, but nevertheless may convey information about the influence of product variety on exports.

3.2 Construction of the stock of technology and product variety

The stock indicators of technology and product variety are based on the inventory perpetual method with a 20% geometric depreciation rate. This depreciation rate for patents and R&D follow the estimates by Parkes and Schankerman (1984). A 20% depreciation rate is also applied to trade marks and model designs following the practice of tax departments. To get as a precise measure of the capital stock as possible, the data starts as early as data are available after 1870. R&D stock data are constructed from 1960, but since R&D data first became available during the 1960s for most countries, the estimates below start from 1965. The R&D expenditure data are deflated by an unweighted average of the GDP deflator and the economy-wide hourly labour costs following Coe and Helpman (1995). The initial stock of R&D, patents, designs, and trade marks is equal to the initial year flow divided by the sum of the depreciation rate (0.2) and the average geometric growth rate over the whole data period. As mentioned above, R&D expenditures are measured as R&D expenditures in the business sector and financed by the business sector.

3.3 Measures of competitiveness in technology and product variety

Multilateral competitiveness indexes that allow for competition from third country exporters and domestic producers in export markets are constructed for prices, the stock of real R&D, patents, trade marks and model designs. The weights in the competitiveness index are computed as the market share of manufacturing sales of producers from country j in market i including the share of sales of domestic producers (country i). This method acknowledges the fact that exporters have

proportionally higher market shares in countries with close geographical and political proximity and, therefore, that exporters across nations face quite different competitors. Export prices or export unit values of manufacturing products are used in the index for export price competitiveness. The technicalities behind the computation of the multilateral competitiveness indexes are relegated to the appendix.

The computation of the competitiveness of the external patent stock is much simpler because the country of residence of the patent applicant and the destination country are identified by the data. The competitiveness index for country j is computed from the following equation:

$$C_j^{FP} = \sum_{i=1}^{18} \frac{FP_i^j}{(FP_i + DP_i)} \frac{EX_i^j}{EX^j},$$

where FP^{iXXX} is the patent stock of exporters in country j destined for market i , FP_i is the external patents stock in country i , DP_i is the domestic patent stock produced by residents in market i , EX_i^j is exports of country j to market i , and EX^j is total exports of country j . The first right-hand term is country j 's share of the patent capital in market i , and the second right-hand fraction is market i 's share of country j 's export.

4. Empirical estimates

A system estimator is used to examine the effects on exports of technology and product variety. A standard export model, where exports are a function of price competitiveness and trade weighted income, is augmented with the technology and product variety indicators that are discussed in the previous sections. The following model is estimated for the 18 OECD countries that are listed in the notes to Figure 1:

$$\begin{aligned} \Delta \ln X_{it} = & \alpha_0 + \alpha_1 \Delta \ln C_{it}^P + \alpha_2 \Delta \ln C_{it}^{R\&D} + \alpha_3 \Delta \ln C_{it}^{Dpat} + \alpha_4 \Delta \ln C_{it}^{Epat} \\ & + \alpha_5 \Delta \ln C_{it}^{Des} + \alpha_6 \Delta \ln C_{it}^{Tm} + \alpha_7 \Delta \ln Y_{it}^{Tw} + \alpha_8 \Delta^2 \ln Y_{it}^{Tw} + \alpha_9 \Delta \ln K_{it}^{R\&D} \\ & + \alpha_{10} \Delta \ln K_{it}^{Dpat} + \alpha_{11} \Delta \ln K_{it}^{Epat} + \alpha_{12} \Delta \ln K_{it}^{Des} + \alpha_{13} \Delta \ln K_{it}^{Tm} + TD_i' \xi + \varepsilon_{it} \end{aligned} \quad (1)$$

where X is manufacturing export volume, C^P is export price competitiveness, $C^{R\&D}$ is R&D stock competitiveness, C^{Dpat} is domestic patent stock competitiveness, C^{Epat} is external patent stock competitiveness, C^{Des} is design stock competitiveness, C^{Tm} is trade mark stock competitiveness, K^{Dpat} is the stock of domestic patents, K^{Epat} is the stock of external patents, $K^{R\&D}$ is the R&D stock,

K^{Des} is design stock, K^{Tm} is trade mark stock, Y^{Tw} is trade weighted income, TD is time dummies, and ε is a disturbance term. The subscripts i signify country i .

The model is estimated using annual data over the period from 1966 to 2000. The starting period is restricted by the availability of R&D data, as discussed in the previous section, and the termination date is 2000 because of a 4-year publication lag for the external patent data as noted earlier. Since the estimated coefficients of country dummies were individually insignificant they were omitted from all estimates. Unrestricted and restricted versions of the model are estimated and the variables are lagged up to two years as discussed below.

The coefficients are restricted to be the same across countries except for the coefficients of trade weighted income because of large cross-country variations. However, to simplify the presentation of the estimates the coefficients of trade weighted income were restricted to be the same in groups using the following procedure. The coefficients were first allowed to vary across countries. The two lowest estimates were tested for equality and merged if the null of equality could not be rejected at the 1-percent level. The third lowest coefficient was merged with this group if the null hypothesis of coefficient equality could not be rejected, otherwise a new group was formed, and so forth. This procedure resulted in a main group of 15 countries and a group consisting of Germany, Spain and Ireland with distinctly higher income elasticities.

To gain efficiency the model is estimated allowing for the correlation of the error-terms between countries. The covariance matrix is weighted by the correlation of the disturbance terms using the following variance-covariance structure:

$$\begin{aligned} E\{\varepsilon_{it}^2\} &= \sigma_i^2, \quad i = 1, 2, \dots, N, \\ E\{\varepsilon_{it}, \varepsilon_{jt}\} &= \sigma_{ij}, \quad i \neq j, \end{aligned}$$

where σ_i^2 = the variance of the disturbance terms for country $i = 1, 2, \dots, N$, σ_{ij} = the covariance of the disturbance terms across countries i and j ; and ε is the disturbance term. The variance σ_i^2 is assumed to be constant over time but to vary across countries and the error terms are assumed to be mutually correlated across countries, σ_{ij} , as random shocks are likely to impact on all countries at the same time. The variance terms, σ_i^2 and σ_{ij} , are estimated using the feasible generalized least squares method.

The results of estimating Equation (1) are shown in Table 2. Several estimates are presented to address the income elasticity puzzle. A traditional export model consisting of price

competitiveness and contemporaneous income is presented first and the model is sequentially extended with the variables included in Equation (1). Common for all the estimates in the table is that the diagnostic tests do not give any evidence against the model specification and the null hypothesis of pooling cannot be rejected at the 1-percent level. Furthermore, the sum of the estimated coefficients of price competitiveness is consistently close to -0.5 across the estimates, which suggests that the estimated price elasticities in foreign trade are very robust to the inclusion of other regressors in the model.

Table 1. Restricted parameter estimates of Equation (1)

	--- 1 ---	--- 2 ---	--- 3 ---	--- 4 ---	--- 5 ---
$\Delta \ln X_{t-1}$	0.08(2.66)	0.24(0.24)	0.23(6.63)	0.15(4.33)	0.14(4.19)
$\Delta \ln C_t^P$	-0.29(11.1)	-0.31(11.7)	-0.27(9.78)	-0.25(9.97)	-0.24(9.58)
$\Delta \ln C_{t-1}^P$	-0.24(9.02)	-0.17(6.19)	-0.22(7.60)	-0.25(9.33)	-0.26(4.16)
$\Delta \ln C_t^{R\&D}$				0.08(2.80)	0.06(2.06)
$\Delta \ln C_t^{Pat}$					0.01(0.41)
$\Delta \ln C_t^{Epat}$				0.16(4.17)	0.16(3.99)
$\Delta \ln C_t^{Des}$					0.00(0.22)
$\Delta \ln C_t^{Tm}$					-0.11(0.66)
$\Delta \ln K_t^{Dpat}$				0.13(3.59)	0.12(2.76)
$\Delta \ln K_{t-2}^{Epat}$				0.13(3.37)	0.13(3.42)
$\Delta \ln K_t^{R\&D}$		-			0.02(0.42)
$\Delta \ln K_t^{Des}$		-			-0.02(3.34)
$\Delta \ln K_t^{Tm}$		-			0.14(0.91)
$\Delta \ln Y_t^{Tw,A}$	2.28(18.7)	1.58(10.1)	0.84(2.92)	0.64(2.23)	0.74(2.61)
$\Delta \ln Y_t^{Tw,B}$	3.70(14.5)	2.80(10.4)	1.47(6.44)	1.50(4.32)	1.58(4.59)
$\Delta^2 \ln Y_t^{Tw}$		0.82(5.83)	1.48(6.43)	0.93(4.17)	0.93(4.16)
DW	1.90	1.99	2.00	1.97	1.95
R_{Buse}^2	0.68	0.74	0.94	0.99	0.99

Notes: The numbers in parentheses are absolute t -statistics. Group A consists of all the countries except the following countries, which are in group B: Germany, Ireland and Spain. Constant terms are included in all estimates but not shown. R_{Buse}^2 is Buse's raw moment R^2 .

Column 1. Competitiveness and trade weighted income.

Column 2. Competitiveness, trade weighted income and acceleration in trade weighted income.

Column 3. Competitiveness, trade weighted income, acceleration in trade weighted income, and time-dummies.

Columns 4 and 5. Competitiveness, trade weighted income, acceleration in trade weighted income, time-dummies, and product variety and technology indicators.

Focussing first on the income elasticity puzzle, the estimates in the first column follow a traditional approach where exports are functions of contemporary income and contemporaneous and a one-period lag of price competitiveness. Further lags of price competitiveness were omitted because their estimated coefficients were insignificant at the 5-percent level. The estimated short-run income elasticities are 2.28 for group *A* and 3.70 for group *B* which are comparable with the income elasticities found in the literature (Marquez, 2002). Clearly, these income elasticities are incompatible with neoclassical demand theory. If manufacturing exports are normal goods we would expect income elasticities close to one. Thus, the estimated income elasticity is likely to reflect omitted variables that are correlated with income.

Adding a one-period-lag of income growth to the model in column 1 yields a negative estimated coefficient of the lagged income growth, which suggests that some of the income-induced exports at period t are deducted from exports in the next period. This implies that both the level and the change in the trade weighted income influence the level of exports. The terms $a\Delta \ln y_t - b\Delta \ln y_{t-1}$ are consequently re-parameterised to $(a-b)\Delta \ln y_t + b\Delta^2 \ln y_t$. Adding the acceleration in income to the model in column 1 reduces the short-run income elasticities significantly by 0.6-0.9 (column 2). The significance of the income acceleration term suggests that growth cycles are influential for exports, but that their effects are temporary. This result is consistent with the cyclicity in the export-income ratio in Figure 1.

Adding time-dummies to the model in column 2 reduces the income elasticities to almost a half compared to the estimates in column 2 (see column 3). The weighted average long-run income elasticity is 0.92, which suggests that estimated income elasticities in traditional export equations are biased upwards because income is highly correlated with factors that are common across countries and that change at the same rate over time such as product variety, integration and technology. Time-dummies have been used to identify integration in the world markets and particularly the effects of changing trade barriers during the interwar period (Madsen, 2001).

The estimates in column 5 extend the estimates in column 3 with technology and product variety indicators. Two lags were initially included in the model but only the estimated coefficient of external patent capital stock was significant at the 5-percent level. Restricting the insignificant coefficient to zero yields the model in the fourth column. The inclusion of the technology and product variety variables implies that long-run income elasticity for the main group

of countries is rendered insignificant at the 1-percent level and is reduced from 1 to 0.6. Furthermore, the estimated coefficient of income acceleration is reduced from 1.5 to 0.9. These results demonstrate that estimated income elasticities in traditional studies are biased substantially upwards due to the omission of variables that account for technology, product variety and integration in the world market. The estimated coefficient of income growth of 1.5 for Germany, Ireland and Spain remains higher than the income elasticity of the main group. This could indicate that the income term captures factors that are important for exports in these countries but that are not accounted for in the estimates.

Turning to product variety and technology, the estimated coefficients of R&D competitiveness, domestic patent capital stock, and the level and competitiveness of external patent stock are highly significant. The estimates show that external patents have two effects on exports. First, they lead to more exports for the exporting country and OECD exports in general, thus being able to explain a significant proportion of the increase in the export-income ratio that has been observed in the post-war period, particularly in the 1990s as shown in the next section. Second, external patents increase the market share of the exporting country. An increasing market share need not be at the expense of other exporters but could fall on domestic producers. The increasing diffusion rate in the post-war period implies that exporters have gained market shares at the expense of domestic producers.

The level of domestic patent stock is also influential for exports, which suggests that producers do not seek external patent protection of innovations that later prove to have export potential, because the expected costs of seeking external protection exceed the *expected* return from the patent. This hypothesis is also consistent with the result that the estimated coefficient of domestic patent competitiveness is insignificant. Producers who file patents on new products in the domestic market only, are not trying to compete in the export markets. Furthermore, the products that they seek domestic patents on are not substitutes to products of potential competitors in export markets.

A remarkable feature of the estimates is that R&D stock is important only for market share. This suggests that R&D expenditures are predominantly targeted at product and technology imitation and not at innovations of truly new products and new technologies. This result is consistent with the correlation analysis in Section 3, which showed that R&D competitiveness was statistically significantly correlated with external patent competitiveness. The result is also consistent with the conjecture of Nadiri (1993) that a significant fraction of R&D is directed

towards imitation and competition and the fact that a large fraction of R&D is of an absorptive nature, in the sense that it is undertaken to understand the frontiers of technology (OECD, 2001). Patents, by contrast, appear to represent innovations of new products and new technologies that increase total exports both within and from the OECD countries.

How do the results compare with other empirical studies? Since external patents have not been considered in earlier studies, the comparison is limited to R&D elasticities and domestic stock elasticities. Anderton (1999), Fagerberg (1988), Greenhalgh (1990), and Magnier and Toujas-Bernate (1994) estimate an average elasticity of technology and product variety competitiveness of approximately 0.3 depending on sector and country. Carlin *et al.* (2001), by contrast, find that the estimated coefficients of patent and R&D competitiveness are not significantly different from zero. These elasticities cannot strictly be compared with the estimates here because these studies use export market shares as a dependent variable and, as such, are only comparable with the estimates here if the ratios of technology to exports are identical across nations. Furthermore, these studies differ from the study here by using R&D expenditures or patents relative to GDP. However, regardless of these differences in the data, the elasticities in Table 1 are in the middle range of the estimates in the literature.

5 Model simulations

The next question is whether the model estimates in the previous section can explain 1) the market increase in exports in the 1990s; and 2) the large cross-country variation in exports in the 1990s. The 1990s are of particular interest because this period distinguishes itself from other periods as the period in which the ICT revolution unfolded and the export-income ratio increased by more than the trend. The period also contains one of the two patent-diffusion waves experienced in the past century, as discussed in Section 2.

The results of simulating the preferred model in the fourth column of Table 1 are displayed in Table 3. The joint effects from the time-dummies and the constant term are 1.83% in the period considered, which is identical for all countries and is, therefore, not shown in the table. A remarkable feature of the simulations is that external patents explain more of the export growth than income for the average OECD country. External patents have annually contributed to a 2.0% growth rate in exports in the period. Adding to this number the effects of the increasing diffusion rate (column 1) suggests that external patents contributed annually to a 2.1% growth in manufacturing exports. The increase in the domestic patent stock added another 0.7% to this growth

rate, which implies that patents jointly explained a 2.8% annual growth in exports for the average OECD country. This is a significant result because it shows that almost half of the increase in exports in the 1990s, are patent-induced. If the effects from the time-dummies are interpreted as integration effects an annual growth rate of 4.6% can be attributed to increasing integration, product variety and technology. Only a merely 2% can be attributed increasing income.

The model also explains the cross country variation in exports well. For the two low export performers, Switzerland and the UK, technology and product variety have contributed to only about 1% annual growth in exports (sum of the first four columns). The corresponding number is about 5% for Denmark, Finland, Ireland, and Spain, which suggests that high innovative activity in these countries accounts for the lion's share of their export success in the 1990s. Finally, it is interesting to note that Japan, which used to be a country with large success in innovation and exports in the 1960s and the 1970s, has only managed to increase exports by 2.1% annually due to innovations in the 1990s.

Table 3. Model predictions, 1990-2000. Average arithmetic growth.

	C^{Epat}	K^{Epat}	$C^{R\&D}$	K^{Dpat}	Y^{Tw}	C^P	X^{Act}
Can	0.32	2.24	0.13	0.82	2.10	0.16	9.12
USA	0.35	2.29	0.00	0.92	1.53	0.60	8.61
Jap	0.08	1.69	-0.03	0.39	1.95	-1.47	3.03
Aus	0.13	2.45	0.24	0.47	1.69	0.97	9.00
Aut	-0.49	1.51	0.24	0.18	1.38	1.92	9.56
Bel	0.32	1.80	0.01	0.68	1.63	-0.47	5.26
Den	0.18	2.50	0.23	1.23	1.60	-0.33	5.86
Fin	0.77	2.92	0.31	0.77	1.46	-0.07	7.01
Fra	-0.47	1.56	-0.06	0.44	1.56	0.61	6.92
Ger	-0.33	1.54	-0.12	0.69	3.81	-0.12	4.86
Ire	1.03	2.66	0.65	0.71	3.88	0.67	14.7
Itl	-0.38	1.48	-0.10	1.10	1.57	-0.09	5.36
Net	0.21	1.86	0.01	0.88	1.57	0.54	6.56
Nor	0.23	2.56	0.00	0.70	1.49	1.06	5.53
Spa	0.65	2.32	0.30	0.63	3.62	0.56	11.1
Swe	-0.30	2.16	0.11	0.82	1.62	0.95	7.16
Swz	-0.50	1.19	-0.16	0.31	1.54	-0.83	3.65
UK	-0.21	1.83	-0.25	0.32	1.71	-0.24	6.21
Average	0.09	2.03	0.08	0.67	1.98	0.24	7.19

Notes. The simulations are based on the estimates in the last column of Table 1. X^{Act} is the actual average growth rate in manufacturing exports during the period.

How much of the cross-country variance in export growth can be explained by the model? The cross-country export variance is 7.9, which reduces to 5.5 when the effects of product variety and technology are allowed for. The variance of 5.5 is further reduced to 3.7 when price competitiveness is allowed for, and further to 2.7 when trade weighted income is allowed for. This exercise suggests that the model explains a very high proportion of the cross-country variance.

6 Concluding remarks

This paper has shown that when technology, product variety and integration are allowed for in export equations 1) the income elasticities of exports decline to levels that are much more consistent with economic theory than estimates from traditional export equations; 2) a large proportion of the cross-country variation in the export performance in the 1990s can be explained by differences in innovative activity; 3) almost half of the export growth in the 1990s was technology and product variety induced; and 4) that R&D stock is *not* influential for the total exports from the OECD countries but only the relative performances among countries, which suggests that R&D, unlike patents, is predominantly used for imitation of innovations and keeping the technology content of products up to the technology frontier.

In a new twist to the story it was shown that exporters' patents applied for in their export markets was the single most important factor behind the surge in exports in the 1990s from the OECD countries. It was influential for exports because it increased the exports in the whole OECD area and, at the same time, crowded out sales of domestic producers. Total external patents contributed to a 2.1% annual growth rate in real exports in the 1990s in the OECD area. Patent stock in total contributed to a 2.8% annual growth in OECD exports in the same period, or a compounded rate of 35% in the period from 1990 to 2000. Furthermore, simulations of the model showed that technology and product variety can account for a significant proportion of the diversity of export growth across countries and over time.

The implications of the empirical findings are substantial. First, external patents hold the key to for success in the export market. Patenting domestically has substantially lower effects on exports than external patents, which suggests that policy measures that influence external patent applications may be much more effective tools for current account targeting than exchange rate realignments. Second, demand management is a blunt instrument for targeting trade balances provided that imports are mirror images of exports. The estimates showed that income elasticities in exports were low, and statistically insignificant for the majority of countries, when technology, product variety and integration were accommodated in the estimates. Income acceleration, however,

was shown to be influential for export growth, which suggests that a significant fraction of income-induced export growth is temporary. Third, the innovative activity in a country cannot be separated from its export performance. The new growth theory suggests that innovations are important for growth in GDP and total factor productivity. Thus, the parallel rise and the subsequent decline of Japan's growth in GDP as well as exports is no coincidence.

DATA APPENDIX

Patents. Canada. *Canada Yearbook*, Statistics Canada, "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil" and Federico, P J, 1964, "Historical Patent Statistics 1791-1961," *Journal of the Patent Office Society*, 46, 89-171. USA. Dosi, G, K Pavitt and L Soete, 1990, *The Economics of Technical Change and International Trade*, New York: Harvester Wheatsheaf, and Federico *op. cit.* Japan. The Department of Finance 23th Financial and Economic Annual of Japan, Tokyo: Government Printing Office, various issues, "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil" and Federico (*op cit*). Australia. Data supplied by the Australian Patent Office and Federico (*op cit*). Austria. *Statistisches Jahrbuch für die Republik Österreich.* Belgium. Federico (*op. cit*) and WIPO. Denmark. Danmarks Statistik, *Statistisk Årbog.* Finland. *Annuaire statistiques de Finlande* and *Statistisk Årsbok För Finland.* France. *Annuaire statistique de la France* and "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil". Germany. "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil" and *Statistisches Jahrbuch Für die Bundesrepublik Deutschland.* Ireland. *Saorstat Eireann, Statistical Abstract.* Italy. "Blatt für Patent-, Muster- und Zeichenwesen, mit Urheberrechts-Teil," *Annuario Statistico*, and Fernando (*op. cit*). Netherlands. "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil" and *Jaarcifers voor Nederland.* Norway. "Statistiske opplysninger vedkommende Patentvæsenet i Norge (1886-1933)," "Norsk tidende for det industrielle rettsvern," (1939-1970), Bjørn L Basberg, 1984, "Patenter og teknologisk endring I Norge 1840-1980. En metodediskusjon om patentdata anvendt som teknologi-indikator," Mimeo, Institutt for Økonomisk Historie, Norges Handelshøyskole, Bergen, "Patentstyret - Styret for det industrielle rettsvern". Spain. WIPO. Sweden. *Statistisk Årsbok för Sverige.* Switzerland. Ritzmann-Blickenstorfer, 1996, *Historical Statistics of Switzerland*, Chronos: Zurich and "Blatt für Patent-, Muster- und Zeichenwesen mit Urheberrechts-Teil". UK. The data were kindly provided by Scott Tilbury, The Patent Office. **Business R&D financed by business.** OECD, *Main Science and Technology Indicators*, OECD, Paris, OECD Archive (OECD-DSTI/EAS), National Science Foundation, Statistics Netherlands. **Manufacturing export volume and export prices.** OECD, *Historical Trade Statistics*, UN, *Statistical Yearbook*, World Bank, *World Tables*, OECD, *Trade Statistics*, Paris. **Trade weighted income:** Total real GDP, OECD, *National Accounts, Vol. 1* in the OECD countries weighted by manufacturing export (OECD, *Trade in Commodities*) for each country in 1981. **Price competitiveness.** 1960-1977, the technological export competitiveness weighting matrix, as derived below, is used as weights and manufacturing export unit values are used as prices. 1977-2002, OECD, *Economic Outlook*.

APPENDIX 1: Calculation of technological export competitiveness

The weighting matrix used to generate the competitiveness index on the export markets is calculated as follows. Define X is a $(n \times m)$ matrix, where the element x_{ij} is exports of country i to country j and n is the number of countries and m is the number of markets. The same suppliers and markets are considered, implying that $n = m$. Given $R = X/(X'c)$ and $V = X/(Xc)$, where c is an $(n \times 1)$ vector, $/$ stands for the Hadamard division, and R is the share of country i 's exports sold in market j , and V is country j 's market share in country i 's market. A combined measure of third market competitor's prices is found by multiplying the technology indicator for all 20 OECD countries by $Z = (R^T V^T) * A$, where R^T is R with zero's main diagonal elements, V^T is V with zero main diagonal elements, $*$ is the Hadamard product, and A is an $(n \times m)$ matrix with all off-diagonal elements equal to 1 and the main diagonal elements equal to 0. This index is combined with the local producer's technology stock directed towards sale in the domestic market, where sales are used as weights. The competitiveness index is then calculated by dividing the technology stock of the domestic producer with the competitors' technology stock.

The data matrix X is calculated using 1981-data for the 18 OECD countries that are used in this study: The diagonal elements are measured as USD manufacturing turnover (UN, *Statistical Yearbook*) minus total USD manufacturing exports (OECD, *Trade in Commodities*, SITC 5, 6, 7, and 8) for each country. The off-diagonal elements are from OECD, *Trade in Commodities*, SITC 5, 6, 7, and 8.

REFERENCES

- Amable, B and B Verspagen, 1995, "The Role of Technology in Market Shares," *Applied Economics*, 27, 197-204.
- Amendola, G, G Dosi and E Papagni, 1993, "The Dynamics of International Competitiveness," *Weltwirtschaftliches Archiv*, 129, 451-471.
- Anderton, Bob, 1999, "Innovation, Product Quality, Variety, and Trade Performance: An Empirical Analysis of Germany and the UK," *Oxford Economic Papers*, 51, 152-167.
- Carlin, Wendy, Andrew Glyn and John Van Reenen, 2001, "Export Market Performance of OECD Countries: An Empirical Examination of the Role of Cost Competitiveness," *Economic Journal*, 111, 128-162.
- Coe, David T and Elhanan Helpman, 1995, "International R&D Spillovers," *European Economic Review*, 39, 859-887.
- Dosi, Giovanni, Kieth Pavitt and Luc Soete, 1990, *The Economics of Technical Change and International Trade*, New York: Harvester Wheatsheaf.
- Eaton, Jonathan and Samuel Kortum, 1996, "Trade in Ideas: Patenting and Productivity in the OECD," *Journal of International Economics*, 40, 251-278.
- Fagerberg, Jan, 1988, "International Competitiveness," *Economic Journal*, 98, 355-374.
- Fagerberg, Jan, 1996, "Technology and Competitiveness," *Oxford Review of Economic Policy*, 12, 39-51.
- Fagerberg, Jan, 1997, "Competitiveness, Scale, and R&D," in J Fagerberg, P Hansson, L Lundberg and A Melchior (eds), *Technology and International Trade*, Cheltenham: Edward Elgar, 38-55.
- Greenhalgh, Christine, 1990, "Innovation and Trade Performance in the United Kingdom," *Economic Journal*, 100, 105-118.
- Greenhalgh, Christine, Paul Taylor and Bob Wilson, 1994, "Innovation and Export Volumes and Prices – A Disaggregated Study," *Oxford Economic Papers*, 46, 102-134.
- Griliches, Zvi, 1990, "Patent Statistics as Economic Indicators," *Journal of Economic Literature*, 28, 1661-1707.
- Grossman, Gene M and Carl Shapiro, 1987, "Dynamic R&D Competition," *Economic Journal*, 97, 372-387.
- Helpman, Elhanan, 1990, "Monopolistic Competition in Trade Theory," Princeton University, Special Papers in International Finance No. 16, Princeton, NJ.

- Jovanovic, Boyan and Peter L Rousseau, 2003, "Two Technological Revolutions," *Journal of the European Economic Association*, 1, 419-428.
- Kaldor, Nicholas, 1978, "The Effects of Devaluations on Trade in Manufactures," in N Kaldor, *Further Essays on Applied Economics*, London: Duckworth.
- Krugman, Paul, 1980, "Scale Economics, Product Differentiation, and the Pattern of Trade," *American Economic Review*, 70, 950-959.
- Krugman, Paul R, 1983, "New Theories of Trade among Industrial Countries," *American Economic Review, Papers and Proceedings*, 73, 343-347.
- Krugman, Paul, 1989, "Differences in Income Elasticities and Trends in Real Exchange Rates," *European Economic Review*, 33, 1031-1049.
- Madsen, Jakob B, 2001, "Trade Barriers and the Collapse of World Trade during the Great Depression," *Southern Economic Journal*, 67, 2001, 848-868.
- Magnier, Antoine and Joel Toujas-Bernate, 1994, "Technology and Trade: Empirical Evidences for the Major Five Industrialized Countries," *Weltwirtschaftliches Archiv*, 130, 494-520.
- Marquez, Jamie, 2002, *Estimating Trade Elasticities*, Boston: Kluwer Academic Publishers.
- Nadiri, Ishaq, 1993, "Innovations and Technological Spillovers," NBER Working Paper No 4423.
- OECD, 1990, *Main Science and Technology Indicators*, No 2, Paris.
- OECD, 2001, "Using Patent Counts for Cross-Country Comparisons of Technology Output," *STI Review*, No 27, Paris:OECD.
- OECD, 2003, *OECD Science, Technology and Industry Scoreboard*, Paris.
- OECD, 2004, *Economic Outlook*, Paris.
- Parkes, Ariel and Mark Schankerman, 1984, "The Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources," in Z Griliches (ed), *R&D, Patents, and Productivity*, Chicago: Chicago University Press.
- Spencer, Babara J and James A Brander, 1983, "International R&D Rivalry and Industrial Strategy," *Review of Economic Studies*, 50, 707-722.