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The relative importance of international *vis-à-vis* national technological spillovers for market share dynamics

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The aim of the paper is to investigate the relative importance of international *vis-à-vis* national technological linkages for international competitiveness for 19 industrial sectors. We estimate a dynamic model with an autoregressive structure in the dependent variable. In the paper competitiveness is captured both by cost competitiveness and by technological competitiveness. The main result is that while national linkages have a positive impact on the trade balance in several sectors (mostly scale intensive and specialised suppliers), this is not the case for international linkages.

1. Introduction

In their book on innovation and growth in the modern economy, Grossman and Helpman (1991: chs 7 and 8) developed two sets of models, in which they made two heroic assumptions in each case, namely that technological spillovers were either purely national in scope or purely international in scope. However, in both cases the authors stressed that they were analysing extreme cases, and that reality would lie somewhere in between pure national and international spillovers (Grossman and Helpman, 1991: 208). Hence, whether national or international spillovers are the most important ones in various contexts is a question left for empirical research. In the words of Grossman and Helpman (1995: 1283):

> Once we recognize that firms may gain knowledge from the experience of others, a question that arises is: What is a set of others from which a given firm learns? There are at least two dimensions to this question. First, does a firm in a given industry acquire technical information from the activities of local firms in other industries? Second, does it gain such information from the activities of firms in its own industry operating in other countries? These are empirical matters that obviously may vary with the particular context one has in mind.

Hence, the key question of this paper concerns the extent to which national and international spillovers (or technological linkages[1]) from other industries affect market shares of countries in different manufacturing sectors. The investigation of the role of technology in explaining international competitiveness has been an important aspiration of a large part of the empirical 'technology-gap' literature on international trade which was initiated with the work of Soete (1981). More recently many papers have provided more sophisticated econometric analyses on this issue also in a dynamic context (e.g. Fagerberg, 1988; Amendola *et al.*, 1993; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995; Verspagen and Wakelin, 1997; for a review, see Fagerberg, 1996). However, only few attempts have been made to incorporate technological linkages in models of market share dynamics either by looking at embodied R&D flows between sectors (Fagerberg, 1997; Laursen and Meliciani, 2000) or by estimating the effect of national and international knowledge stocks for trade performance (Gustavsson *et al.*, 1999).

Whether national *vis-à-vis* international technology flows are of prime importance to competitiveness in different sectors is evidently of importance for, for example, theories of national systems of innovation (Freeman, 1987; Nelson, 1993). In addition, Grossman and Helpman (1991) have shown that if national spillovers prevail, then initial conditions matter for determining the pattern of trade and rates of innovation (and possibly growth rates). On the other hand, if international spillovers dominate, then long-term patterns of specialization are to a large extent determined by countries' relative factor endowments (in the broad sense of the word, i.e. including human capital), and the initial pattern of specialization will matter only to a small extent.

In previous research (Laursen and Meliciani, 2000) we have shown that national technological linkages are important for maintaining and acquiring market shares on the OECD market. In particular, within-sector technological activity plays the largest role in science-based industries, upstream linkages in scale-intensive and downstream linkages in specialized supplier types of industries. By 'upstream linkages' we mean the importance of the other sectors as suppliers of embodied R&D (measured as input/output coefficients weighted by R&D expenditures in the *supplier* sectors) for the sector in question, and by 'downstream linkages' we mean the importance of the other sectors as users of embodied R&D for the sector in question (measured as output coefficients weighted by R&D expenditures in the *user* sectors).[2] Hence, the latter measures the 'quality' of the national users' demand for a given product. However, no measure of international technological linkages (or 'spillovers') was included in the analysis. Hence, the main contribution of this paper is to include such a variable, reflecting embodied international R&D flows.

[1]For a discussion of the similarities and differences between the concepts of spillovers and technological linkages/technological interdependencies, see Laursen and Meliciani (2000).

[2]For a more detailed definition of these variables see Laursen and Meliciani (2000). For the distinction between input/output and output coefficients in calculating forward and backward linkages, see e.g. Jones (1976).

The paper is structured as follows. Section 2 contains a theoretical discussion on the nature of technological interdependencies (or spillovers). Section 3 describes the data and the variables to be applied, while Section 4 depicts the econometric specification used. In Section 5 our estimations are presented and discussed. Finally, Section 6 concludes.

2. A theoretical discussion of national and international spillovers

2.1 Introduction

In orthodox trade theory (Ohlin, 1933; Heckscher, 1949; Jones, 1965), technology plays no role in determining trade flows, since agents are not able to appropriate the economic benefits from technological innovation. However, in new trade theory as well as in evolutionary accounts of trade, technology plays a central role. In new trade theory technology either enters as an interpretation of economies of scale (e.g. Krugman, 1980, 1987) or as knowledge that can be absorbed by human capital (e.g. Grossman and Helpman, 1991; Grossman, 1992). In theoretical models involving internal economies of scale (e.g. Krugman, 1980), firm-internal knowledge can be one reason for such internal economies of scale, while in models of external economies (e.g. Krugman, 1987), knowledge accumulated within the industry (of both foreign and national origin) can be a reason for such external economies. However, apart from the trade models encompassing internal economies of scale, the models can be seen to be frameworks, where any assumption on the nature of spillovers is undetermined.

2.2 National spillovers

It can be observed that the evolutionary representation of technical change emphasizes the tacit and cumulative nature of technological knowledge as opposed to information. The importance of tacit knowledge should therefore limit the scope of knowledge spillovers since it means that there are important capabilities that are embodied in the procedures and routines of firms (Nelson and Winter, 1982; Dosi *et al.*, 1990). However, technology has also a public side. As Dosi (1988) observes:

> . . . firms produce things in ways that are differentiated technically from the products and methods of other firms and that they make innovations largely on the basis of in-house technology, but with some contributions from other firms, and from public knowledge. (Dosi, 1988: 1130)

Nevertheless, such contributions from other firms may then, given the assumed importance of tacit knowledge within the evolutionary perspective, tend to be predominantly national.

The trade literature, emphasizing the importance of country-specific technological development, under the heading of 'technology gap theory' has (at least) two subcategories. One approach is occupied with the importance of technologies developed within the same sector as a driving force behind international trade (Posner, 1961; Hufbauer, 1970; Krugman, 1985). Another tradition is concerned with the role of the size and quality of the domestic market as an inducement mechanism for technological change, and hence also as a determinant of international trade (Linder, 1961; Vernon, 1966; Krugman, 1980). Basically, Posner (1961) assumes that the benefits from technological innovation can be appropriated either by the firm which created the original innovation or by firms within the national industry—at least in the short to medium term. From this perspective we should expect 'own' sector R&D to be an important determinant of trade flows. Linder (1961) and later Vernon argued that the contribution from firms to the technological knowledge of other firms is positively related to the degree of national upstream–downstream user–producer interaction (or 'learning-by-interacting', Lundvall, 1992) and therefore the diffusion of knowledge tends to be localized. In other words, if technological linkages between sophisticated users and producers of technology—within the national economy—obtain, such linkages will positively affect the competitiveness of both users and producers of technologies. Therefore, we would from this perspective, expect technological linkages to other sectors in the domestic economy to be important determinants of trade flows.

2.3 International spillovers

Although the vast majority of literature focuses on the role of country-specific technological change, international trade can also be an important source of learning. In the words of Paul Krugman:

> Discussion of external economies in trade often assumes that these economies do not spill across national boundaries. This is, however, not realistic—surely firms can learn from the experience in other countries, though perhaps not as well as they can from other domestic firms. (Krugman, 1987: 43)

Moreover, Pasinetti (1981) stresses the supremacy of learning compared to cost advantages in international trade: while cost advantages are once-only gains that would be lost if international trade were stopped, learning has permanent effects on the economic performance of trading countries. One such source of learning is the national and international diffusion of technology through technology embodied in goods and services. In the words of Dosi *et al.* (1990):

> . . . the process of diffusion of an innovation (say, a new machine) in a user sector is, in essence, a process innovation and technological change for the user itself. In other words, far from being simply a decision of buy-and-use, diffusion will involve a process of learning, modification of the existing organisation of production and, often, even a modification of products. An important consequence is that the process of adoption of innovations is also affected by the technological capabilities, production strategies, expectations, and forms of productive organisation of the users. One can

> find here the first reason why the empirical evidence shows relatively slow diffusion patterns over time . . . the 'pecking order' in the adoption process is influenced by technological asymmetries in the user sector. (Dosi *et al.*, 1990: 119)

There might be several reasons for learning taking place through international channels in addition to national ones. First, although interaction between users and suppliers is likely to be easier within a country or certain location, such interaction need not be local or national. In other words, it is perfectly possible that users and suppliers interact in developing new technology across national borders. Second, while the exchange of products is in many cases likely to be more anonymous (i.e. not involving qualitative information flows) between suppliers and users situated in different countries, the competence (or 'absorptive capacity' cf. Cohen and Levinthal, 1990) of the users in adopting technology embodied in goods and services is still of utmost importance. By incorporating a measure of such international technological linkages, we aim in this paper at capturing the relevance of the process of learning through international trade. However, as multinational corporations (MNCs) play an important role in this context, they deserve some mention. First, MNCs may transfer technology embodied in goods and services through trade both between and within themselves. Second, MNCs may be considered an efficient way of transferring technology by means of foreign direct investment (FDI). Access to superior foreign technology and management practices in foreign-owned subsidiaries is generally believed to increase performance, not only of the foreign-owned subsidiaries of the MNCs, but also of locally owned firms, because of spillovers from the foreign-owned subsidiaries to the locally owned firms (for an analysis of FDI-related spillovers, see e.g. Hanel, 1997). While we take into account the primary role of MNCs in relation to spillovers (embodied in goods and services), we do not in the present paper incorporate the role of FDI as a possible source of international spillovers, due to the lack of data at the sectoral level for our sample of countries.

2.4 Previous empirical findings on the scope of spillovers

The largest body of literature on the issue of technological spillovers is the productivity literature. One of the pioneering contributions within this tradition, looking at the effects of national versus international spillovers, is due to Coe and Helpman (1995). They construct domestic and foreign knowledge stocks, where the latter is the foreign R&D stock, estimated as the bilateral import-share weighted average of the domestic R&D stock of each country's trading partners. From the analyses the authors conclude that both domestic R&D, as well as international spillovers, are important determinants of (domestic) total factor productivity, since the effects seem to be of about the same strength. Eaton and Kortum (1996, 1997) develop a model of growth and technology diffusion that they fit to aggregate data from OECD countries. They find that innovations in the United States and Japan have made an important contribution to growth in other countries. However, it should be noted that these studies, as well as other subsequent contributions (e.g. Engelbrecht, 1997; Lichtenberg and van Pottelsberghe de la Potterie, 1998)[3] assume that all innovation activity is equally relevant to other innovation activities. However, it is for instance by no means certain that firms in the industrial chemical industry will benefit from R&D conducted in the automobile industry, at least not to the same extent as they would benefit from R&D undertaken by firms in the pharmaceutical industry. This problem can be overcome by using either firm-level or industry-level data. Verspagen (1997) uses industry-level data and confirms that both national and international spillovers are determinants of productivity, both regarding pure knowledge spillovers and rent spillovers.[4] However, the strength of the intranational versus international spillovers appears to depend on which aspect of the data is under scrutiny. If the cross-sectional (the 'between' estimates) dimension is considered, the domestic spillovers appear to be stronger than the foreign ones. If one looks at the time-series dimension, however, the foreign spillovers seem stronger (the 'within' estimates). Other studies confirm that the effect of foreign spillovers are weaker than domestic ones when using 'between' estimates (e.g. Gittleman and Wolff, 1995). Branstetter (1996) supplies firm-level evidence,[5] using a sample of US and Japanese high-tech, publicly traded firms belonging to five different sectors. The methodology allows for the calculation of 'technological distance' between the firms in the sample. That is, if two firms have similar patent portfolios, the R&D undertaken by the counterpart is considered to be highly relevant for the firm in question. Therefore, a firm will make a large contribution to the potential knowledge pool of another firm (domestic or foreign), if the patent portfolios held by the two firms are similar. Using such a set-up, and while taking US patents as the dependent variable, she finds that intranational spillovers are stronger than international spillovers. Jaffe and Trajtenberg (1999) use patent citations to measure international knowledge flows and find that patents whose inventors reside in the same country are more likely to cite each other than inventors from other countries.

While spillovers or technological interdependencies have been a major concern in the growth (productivity) literature, only a few papers have dealt with this issue in the empirical trade literature. Fagerberg (1997) examines the effect of domestic and foreign

[3]Also these contributions found potent (trade-related) international spillovers.

[4]It can be useful to distinguish between rent spillovers, as opposed to pure knowledge spillovers as done in a seminal paper by Griliches (1979). *Rent spillovers* consist of the R&D embodied in purchased inputs. One example of this type of spillover is the contribution to aggregate productivity from the computer industry. Because of competitive pressure within the industry, the full effect could not be appropriated by the industry itself, but instead improved the productivity of purchasing firms in other industries. In contrast to rent-spillovers, Griliches argues that real *knowledge spillovers* are the ideas borrowed by the research teams of industry i from the research results of industry j, and that it is not clear that this kind of borrowing is necessarily related to input purchase flows.

[5]Other firm-level analyses include Basant and Fikkert (1996), who report positive effects on the productivity from domestic and foreign spillovers, for a sample of Indian firms. The two spillover variables are not, however, for reasons of multicollinearity, entered into the same equation.

R&D on export market shares, in a pure cross-section (for the year 1985), using a combination of OECD input–output tables and R&D statistics. He finds that indirect R&D from domestic sources appears to be more conducive to competitiveness than indirect R&D from abroad. Gustavsson *et al.* (1999) examine the effect of national and international knowledge stocks for trade performance—calculated in a similar way to that of Coe and Helpman (1995). However, while the authors find evidence of a positive impact from both types of spillovers, they do not discriminate between the two types, as they are included in separate estimations.

Common for almost all (apart from Fagerberg, 1997; Verspagen, 1997) of the studies surveyed in this section is that they apply either macro data, or report sector-invariant estimates (i.e. all sectors or firms are pooled). Hence, no room is left for the analysis of sectoral differences in the importance of intranational or international technological interdependencies. In the empirical section of this paper we shall allow for such sectoral differences while looking at the sectoral data in a panel data perspective. In particular we expect that 'own' sector technology has a larger impact in high-technology sectors, while domestic and international linkages should be more important in those industries that acquire technology through the purchase of intermediate goods. In the framework of the Pavitt taxonomy (1984) these should be scale-intensive and supplier-dominated industries. National spillovers should matter more than international spillovers in those sectors where technology is more difficult to transfer so that its diffusion requires a high degree of personal user–producer interactions.

3. The data and variables

The data applied in the paper consist of US patents statistics (US Patent Office), the OECD bilateral database, the OECD STAN database, the OECD input–output database, and the OECD ANBERD database over the period 1973–1991. Cost competitiveness is generally measured by either wages per employee or unit labour costs. Here we use unit labour costs since the level of wages *per se* can be related to labour productivity and therefore its effects on export shares might be ambiguous. A second variable which should also capture price competitiveness is the nominal exchange rate.

Different contributions have used different proxies in order to measure technological competitiveness. The most used measures of disembodied technology are R&D and patent statistics: the former is better suited to capture the inputs to the innovation process, while the second is a measure of the innovation output. In this context it is important to note that appropriability of R&D expenditures is likely to be lower than of patents, since it is an input measure from which a larger part of the benefit presumably spills over to other firms/sectors. Following this line of argument, we apply R&D expenditures for what regards technological linkages between sectors, while we use US patent statistics for measuring the 'own sector' technological activity, since it is a more accurate proxy for proprietary knowledge.

The calculation of the international R&D flow variable is displayed in Figure 1.

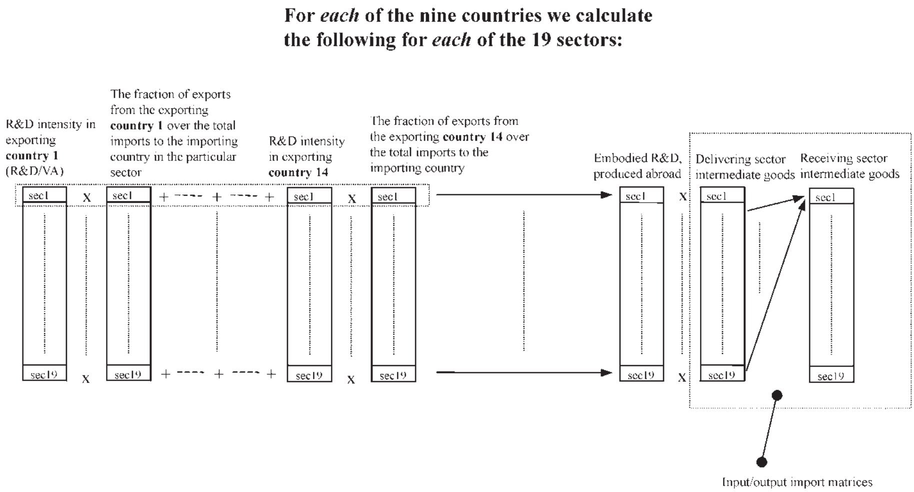

Figure 1 Calculation of the international spillover variable.

Basically, we have input–output import matrices for all the nine OECD countries in our sample. However, since the source of imports stems from many countries with different R&D intensities—within the same industries—we need to calculate the relevant R&D intensity in some way, as this figure is not directly available. As shown in Figure 1, we do this by calculating R&D intensities for 14 trading partners of the nine countries in our analysis,[6] and then subsequently multiplying the figure by each of the 14 countries' exports to the country in question, before adding up the figures across the 14 countries. Calculated in this way the R&D intensity in sector *i* of country *j* is more important to country *z*, if country *z* imports relatively large quantities from country *j* (in sector *i*).

To sum up, the estimations carried out in the paper aim at explaining market share dynamics by means of exchange rates, unit labour costs (as a reflection of production costs), patent statistics (an indicator of within-sector technological development), and the measure of upstream technological linkages. We then add the variable reflecting international flows of embodied R&D in order to see whether such linkages (or international spillovers) matter for gaining or losing market shares, over time.

[6]The choice of only 14 trade partners is dictated by the lack of data on R&D and/or value added for other relevant countries. However, the imports from the 14 other countries as a percentage of total imports make up the majority of imports for all nine countries in most of the 19 sectors in our analysis. The unweighted averages of these percentages, across the 19 sectors in the analysis, for each of the nine countries are (1991): Australia 66%, Canada 82%, Germany 65%, Denmark 79%, France 70%, the United Kingdom 67%, Japan 57%, The Netherlands 66%, and the United States 60%. Moreover the countries we consider include those with the highest R&D expenditures, therefore the R&D embodied in the imports from the remaining trade partners is not likely to be much.

4. The econometric specification

The model used in this paper is a dynamic model with an autoregressive structure in the dependent variable, and is similar to the model developed by Amendola *et al.* (1993). In evolutionary theories using Fisher equations (i.e. applying ‘replicator dynamics’), units with above-average ‘fitness’ expand at the expense of less fit units (for a discussion of the use of Fisher equations in economics, see Silverberg, 1988). The model to be applied in this paper has an evolutionary interpretation as specifying the selection dynamics linking competitiveness (‘fitness’) and expansions or contractions of export shares at the sectoral level. Competitiveness is captured both by cost competitiveness and by technological competitiveness. However, it should be noted that we are considering bilateral competitiveness in the particular set-up used here. Countries whose competitiveness is above (below) a given trade partner will improve (worsen) the trade balance *vis-à-vis* the trade partner within each sector over time.

The econometric specification of the model with an autoregressive structure of the dependent variable should capture several cumulative mechanisms that reinforce the competitiveness of firms on international markets, hence the econometric model is also consistent with the evolutionary economics approach (Nelson and Winter, 1982). Since the process of learning has sector specificities and the balance between tacit and codified knowledge varies across industries, we estimate the model at the sectoral level, as opposed to the aggregate model (country-level) estimated by Amendola *et al.* Like in the case of Magnier and Toujas-Bernate (1994) we allow the slopes to differ in the sectoral dimension. Moreover—and as pointed out above—we follow Verspagen and Wakelin (1997) in analysing bilateral trade performance, rather than trade performance at the level of the aggregate OECD market as done in most other papers in the field. This functional specification assumes that there are two different effects that influence the bilateral trade balance of countries (Verspagen and Wakelin, 1997: 184). The first effect has to do with the country differences in a number of (‘real’) variables underlying competitiveness (production costs and various aspects of technology). The second effect has to with the assumption that differences in real competitiveness between countries can be counterbalanced by changes in the exchange rate. In this way, countries that are relatively competitive, and thus see their trade balance increase, will feel a pressure to appreciate its currency. Depending on the price elasticity for the good in question, the effect of, say, an appreciation of the exchange rate will be positive or negative.

Adopting the autoreggresive representation on the variables we obtain:

$$TB_{izjt} = \alpha_1 TB_{izjt-1} + \alpha_2 PAT_{izjt} + \alpha_3 ULC_{izjt} + \alpha_4 EXC_{zjt} + \alpha_5 DL_{izjt} + \alpha_6 FL_{izjt} + \alpha_{7i} + \alpha_{8z} + \alpha_{9j} + e_{izjt} \quad (1)$$

where TB_{izjt} is the trade balance of country z with country j, in sector i, at time t. PAT_{izjt} is relative patents (patents of country z divided by patents of country j) in sector i, at time t, ULC is relative unit labour costs, EXC is the relative nominal exchange rate, DL is relative domestic technological upstream linkages, FL is relative foreign technological upstream linkages, α_{7i} is a sector-specific effect, α_{8z} and α_{9j} are country-specific effects, and e is the error term. All variables are in logarithms. All regressors, with the exception of the exchange rate, vary in the cross-country, cross-sector and time-series dimension. Obviously the exchange rate only varies across countries and over time. We assume all slope coefficients (with the exception of the coefficient on the lagged dependent variable) to vary across sectors but we impose homogeneity across countries and over time. Future investigations could focus on possible differences in the estimated parameters for countries with different characteristics (e.g. large and small countries). We also assume, as it is standard in this literature, weak exogeneity of all explanatory variables. The variables are defined in detail in the Appendix. This specification allows us to obtain only indirect estimates of long-run multipliers; in order to obtain direct estimates we can reformulate (1) as follows:

$$TB_{izjt} = \beta_1 (TB_{izjt} - TB_{izjt-1}) + \beta_2 PAT_{izjt} + \beta_3 ULC_{izjt} + \beta_4 EXC_{zjt} + \beta_5 DL_{izjt} + \beta_6 FL_{izjt} + \beta_{7i} + \beta_{8z} + \beta_{9j} + e_{izjt} \quad (2)$$

where $\beta_1 = -\alpha_1/(1 - \alpha_1)$, $u = e/(1 - \alpha_1)$ and $\beta_k = \alpha_k/(1 - \alpha_1)$ with $k = 2, \ldots, 9$. In this equation, which can be obtained by deducting $\alpha_1 TB_{izjt}$ from each side of (1), the coefficients on the independent variables are the long-run multipliers. Equation (2) is estimated by pooled least-squares with dummy variables (LSDV) for country and sector fixed-effects. Equation (2) requires instrumental variables to be estimated. Applying an instrumental variable estimator to a reformulated equation such as (2), with the set of instruments given by all explanatory variables in the original equation, allows obtaining the same long-run estimates which can be computed indirectly from the OLS estimation of (1) (Wickens and Breusch, 1987).

It is well known that the LSDV model with a lagged dependent variable generates biased estimates when the time dimension of the panel is small. Judson and Owen (1999) show that the LSDV bias of the coefficient on the lagged dependent variable can be sizeable even when $T = 20$. In this case they show that a corrected LSDV estimator is the best choice when the panel is balanced, otherwise the generalized method of moments (GMM) or the Anderson–Hsiao (AH) estimators are second best solutions. However, the difference in the root mean square error (RMSE) of the coefficient of the lagged dependent variable using the GMM, the AH estimator and the LSDV estimator is not large (see Judson and Owen, 1999: table 2). Moreover the bias of the estimates of the other coefficients is relatively small and cannot be used to distinguish between estimators. Since our interest relies mostly on the sign and significance of these coefficients (and not on the magnitude of the coefficient on the lagged dependent variable), we use LSDV.

5. Econometric results

Table 1 reports the results of the estimation for each of the sectors. The dynamic specification allows estimating both the long-run as well as the short-run impact of each

Table 1 Regression results: explaining the trade balance (no. of observations = 10 000)

Sector	α_{pat}	β_{pat}	α_{ulc}	β_{ulc}	α_{exc}	β_{exc}	α_{dl}	β_{dl}	α_{fl}	β_{fl}
Food, drink and tobacco	–0.104	–0.265	0.240	0.607	0.167	0.423	–0.015	–0.038	0.167	0.424
	(–2.100)	(–2.120)	(3.690)	(3.720)	(2.160)	(2.150)	(–0.260)	(–0.260)	(2.210)	(2.230)
Textiles, footwear and leather	0.062	0.157	0.356	0.901	0.361	0.913	0.068	0.173	–0.059	–0.150
	(1.950)	(1.930)	(5.090)	(5.040)	(4.290)	(4.270)	(1.300)	(1.310)	(–1.070)	(–1.090)
Industrial chemicals	0.196	0.498	0.082	0.206	0.071	0.180	0.129	0.326	0.011	0.028
	(1.740)	(1.740)	(1.370)	(1.370)	(0.700)	(0.700)	(2.470)	(2.460)	(0.120)	(0.120)
Pharmaceuticals	–0.037	–0.094	0.010	0.025	0.478	1.212	0.171	0.433	–0.098	–0.247
	(–0.350)	(–0.350)	(0.110)	(0.110)	(2.600)	(2.610)	(1.540)	(1.530)	(–1.860)	(–1.880)
Petroleum refineries	–0.106	–0.269	0.070	0.178	0.266	0.673	–0.190	–0.481	–0.161	–0.407
	(–1.100)	(–1.100)	(0.460)	(0.470)	(0.750)	(0.750)	(–1.060)	(–1.060)	(–0.800)	(–0.800)
Rubber and plastics	0.317	0.802	0.046	0.118	0.669	1.694	0.250	0.632	–0.019	–0.048
	(3.470)	(3.420)	(0.630)	(0.630)	(5.420)	(5.340)	(3.100)	(3.140)	(–0.370)	(–0.370)
Stone, clay and glass	0.024	0.061	0.182	0.460	0.516	1.308	0.163	0.412	–0.164	–0.416
	(0.290)	(0.290)	(2.040)	(2.050)	(4.950)	(4.910)	(2.460)	(2.460)	(–2.690)	(–2.710)
Ferrous metals	–0.209	–0.529	0.233	0.589	0.263	0.666	0.084	0.212	–0.298	–0.755
	(–2.010)	(–2.000)	(1.500)	(1.510)	(1.330)	(1.340)	(0.640)	(0.640)	(–2.650)	(–2.650)
Non-ferrous metals	–0.009	–0.023	0.379	0.961	0.130	0.329	–0.166	–0.420	0.023	0.058
	(–0.130)	(–0.130)	(3.090)	(3.120)	(0.620)	(0.620)	(–1.130)	(–1.130)	(0.100)	(0.100)
Fabricated metal products	0.120	0.303	0.061	0.154	0.353	0.895	0.160	0.406	–0.010	–0.025
	(2.000)	(1.990)	(0.890)	(0.890)	(4.680)	(4.560)	(3.960)	(3.960)	(–0.210)	(–0.210)
Non-electrical machinery	0.545	1.382	–0.068	–0.173	0.488	1.235	0.083	0.209	0.041	0.104
	(6.950)	(7.040)	(–1.210)	(–1.210)	(6.230)	(6.050)	(3.220)	(3.220)	(0.760)	(0.760)
Office machines and computers	0.378	0.958	0.136	0.345	0.010	0.026	–0.068	–0.172	0.008	0.019
	(4.980)	(5.220)	(2.230)	(2.240)	(0.070)	(0.070)	(–2.660)	(–2.680)	(0.300)	(0.310)
Electrical machinery	0.143	0.361	0.062	0.157	0.224	0.567	0.119	0.302	–0.065	–0.164
	(1.970)	(1.980)	(1.130)	(1.130)	(2.770)	(2.740)	(2.450)	(2.460)	(–1.560)	(–1.570)

Table 1 *Continued*

Sector	α_{pat}	β_{pat}	α_{ulc}	β_{ulc}	α_{exc}	β_{exc}	α_{dl}	β_{dl}	α_{fl}	β_{fl}
Comms. equip. and semiconductors	0.184	0.467	0.008	0.019	0.405	1.026	–0.111	–0.280	0.099	0.250
	(1.860)	(1.870)	(0.130)	(0.130)	(3.320)	(3.310)	(–0.970)	(–0.970)	(1.110)	(1.110)
Shipbuilding	–0.039	–0.099	0.064	0.162	0.989	2.505	0.064	0.161	–0.047	–0.118
	(–0.310)	(–0.310)	(0.350)	(0.350)	(2.940)	(2.960)	(0.440)	(0.440)	(–1.120)	(–1.120)
Other transport	–0.253	–0.642	–0.081	–0.205	1.119	2.833	0.245	0.622	0.223	0.565
	(–1.130)	(–1.130)	(–0.620)	(–0.620)	(2.430)	(2.400)	(1.310)	(1.310)	(1.310)	(1.310)
Motor vehicles	0.371	0.940	–0.238	–0.604	0.897	2.273	0.111	0.282	–0.164	–0.416
	(4.130)	(4.140)	(–1.690)	(–1.690)	(5.760)	(5.660)	(1.240)	(1.250)	(–2.450)	(–2.450)
Aerospace	0.045	0.114	0.149	0.379	0.564	1.427	0.135	0.341	–0.188	–0.477
	(0.100)	(0.100)	(0.850)	(0.850)	(1.370)	(1.370)	(1.220)	(1.210)	(–0.980)	(–0.970)
Instruments	0.186	0.471	0.018	0.047	0.251	0.635	–0.009	–0.023	–0.085	–0.216
	(2.640)	(2.660)	(0.310)	(0.310)	(3.570)	(3.550)	(–0.280)	(–0.280)	(–1.330)	(–1.330)
Adjusted R^2 (short run)	0.879									
Root MSE (short run)	0.709									
Root MSE (long run)	1.796									
Ljung and Box	7.416									

Critical *t*-values are 2.58, 1.96 and 1.64 at the 1, 5 and 10% levels respectively.

variable; the first is referred to as β and the second as α in Table 1. Autocorrelated error diagnostic is implemented via the Ljung and Box (LB) test for three year lags. The estimated value of the LB is below 7.82, the critical value of χ^2 with three degrees of freedom, at the 5% level of significance. All *t*-values are heteroscedasticity consistent.

The results highlight the important role played by technology in affecting international competitiveness. Patents have a positive and significant impact on the trade balance in many sectors. These include especially high-technology sectors (office machines and computers; electrical machinery; communication equipment and semiconductors; instruments) and medium-technology sectors (industrial chemicals; motor vehicles; non-electrical machinery; rubber and plastics) but also some low-technology sectors (fabricated metal products; textiles, footwear and leather).[7] Among high-technology sectors where we would expect patents to show up with a positive and significant sign, the results are inconsistent with expectations in two sectors only: aerospace and pharmaceuticals. Note, however, that these are sectors with very special characteristics. In the pharmaceutical sector there are government regulations that can limit trade, and people can have preferences for domestic products, and in aerospace the technological level of the sector may reflect military-oriented R&D expenditures. In the case of aerospace, Verspagen and Wakelin (1997) find a significant and negative impact of R&D expenditures on the trade balance. In general, our results concerning the importance of direct technology (patents) are consistent with previous findings (e.g. Soete, 1981; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995) in the sense that although the evidence of such an impact is not confined to high-technology sectors, the evidence is strongest for these sectors (see Fagerberg, 1996: 46).

Among the two variables capturing price competitiveness, the exchange rate performs better than unit labour cost. Depending on whether the Marshall–Lerner conditions are satisfied, depreciation can worsen or improve the trade balance. We find that in all sectors depreciation (an increase) of the exchange rate improves the trade balance. Moreover, the variable is significant in many sectors, both high and low tech (food, drink and tobacco; textiles, footwear and leather; pharmaceuticals; rubber and plastics; stone, clay and glass; fabricated metal products; non-electrical machinery; electrical machinery; communication equipment and semiconductors; shipbuilding; other transport; motor vehicles; instruments). On the other hand, unit labour costs are rarely significant and when they are significant they show up with the positive sign in most cases (this is the case for food, drink and tobacco; textiles, footwear and leather; stone, clay and glass; non-ferrous metals; office machines and computers). Only in the motor vehicle sector do we find a negative and significant impact of unit labour costs

[7]The classification is taken from the OECD (1996). High-tech: aerospace; office machines and computers; communication equipment and semiconductors; electrical machinery; pharmaceuticals; instruments. Medium-tech: industrial chemicals; rubber and plastics; non-ferrous metals; non-electrical machinery; motor vehicles; other transport. Low-tech: food, drink and tobacco; textiles, footwear and leather; petroleum; stone, clay and glass; iron and steel; fabricated metal products; shipbuilding.

on the trade balance. It is worth observing, however, that our dependent variable is in current prices, therefore an increase in costs and prices is expected to have an ambiguous impact on the value of exports. Another possible explanation is that high wages could be a proxy for high levels of human capital. However, this explanation would not hold if a high level of human capital leads to a high level of labour productivity, since in this case high unit labour costs would not necessarily be associated with high levels of human capital. In general, it can be noted that unit labour costs (part of production costs) perform differently in our case from other previous studies (including Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995), since these studies find negative and significant parameters in many cases. However, we also include another proxy for price competitiveness, i.e. the exchange rate. In general, it should be said that the evidence is somewhat mixed as to the sectors in which production cost variables matter (see also Fagerberg, 1996: 46). Finally, Amendola *et al.* (1993) find cost competitiveness to have a negative and significant impact on aggregate export shares in the short term only.

As far as the importance of international *vis-à-vis* national technological spillovers is concerned, the evidence points clearly to the prevalence of national technological spillovers (or linkages). Upstream linkages have a positive and significant impact on the trade balance in several industries (industrial chemicals; rubber and plastics; stone, clay and glass; fabricated metal products; non-electrical machinery; electrical machinery). These results are broadly consistent with those found in Laursen and Meliciani (2000), who considered export shares. In fact, we found upstream linkages to have a positive impact on the bilateral trade balance in scale-intensive industries [three of the six sectors where the variable is positive and significant in this study were classified as scale intensive in Laursen and Meliciani (2000): rubber and plastics; stone, clay and glass; fabricated metal products]. Moreover the variable is significant also in two out of three sectors which were classified as specialized suppliers (non-electrical machinery; electrical machinery).

While domestic linkages appear to play a positive role on the trade balance in several sectors, this is not the case for foreign linkages. Foreign linkages or international spillovers seem to have no impact on the trade balance in most sectors. The only industry where international linkages appear to play a positive and significant role is food, drink and tobacco. This is a sector where we would expect the variable to be positive and significant. However, in many other supplier-dominated industries the variable is not significant. Moreover, it is negative and significant in four industries (pharmaceuticals; stone, clay and glass; ferrous metals; motor vehicles). The fact that international spillovers do not appear to play a positive role on the trade balance in most sectors could depend on how the variable is defined. In fact, an increase in the flows due to imports will have an automatic effect on the trade balance through the diagonal term of the import input–output tables.[8] For this reason we have estimated

[8]In the import input–output tables the sum of row i (+ final consumption) makes up the total import of commodity i and is half of the trade balance. What goes into the spillover variable is the input of

the model including also an international spillover variable in which the diagonal terms are excluded. Also in this case international spillovers play a positive and significant impact in few industries only (three out of 19). Moreover, they have a negative and significant impact in five industries.[9]

The results of this paper can be compared to those of Fagerberg (1997), although the empirical set-ups differ markedly. Fagerberg looks at the impact of national and international spillovers on export performance in the entire market of his sample of ten OECD countries, while this paper looks at the impact on the bilateral trade balance. Fagerberg uses two linkage variables as independent variables. The first is the sum of domestic and international linkages and the second expresses international linkages over total linkages. The first variable is positive and significant, while the second is negative and significant. This means that domestic linkages are more important than international ones (this is in accordance with the present paper), but it is difficult to conclude whether international linkages just matter less or whether they do not matter at all (as it is the case in this paper for most sectors).

6. Conclusions

The aim of this paper has been to investigate the relative importance of international *vis-à-vis* national technological spillovers for international competitiveness. The main result of the paper is that while national linkages have a positive impact on the trade balance in several sectors (mostly scale intensive and specialized suppliers), this is not the case for international linkages. These results have important implications. First, Grossman and Helpman (1991) have shown that if national spillovers prevail, then initial conditions matter for determining the pattern of trade, rates of innovation and possibly growth rates. This result, which is relatively new and is still perceived as a 'special case' in the neoclassical trade and growth literature, is at the core of evolutionary theories of trade (Dosi *et al.*, 1990) and growth (Nelson and Winter, 1982). Second, the prevalent role of national linkages in affecting the trade balance points to the importance of national elements for the diffusion of technology. The role of user–producer interactions for the diffusion of technology has been stressed in the literature on national systems of innovation (Lundvall, 1992). Third, the fact that firms learn more easily from other firms within the same country is consistent with the local, tacit and firm-specific character of technology as depicted in the evolutionary tradition.

This study has also confirmed the importance of technology for international competitiveness as stressed in the technology gap approach to trade. Finally, among cost variables, we have found that movements in the exchange rate affect the trade balance

other commodities into commodity i (we are considering the columns of the input–output tables). A possible source of negative correlation between the trade balance and the international spillover variable is the diagonal term of the import/output tables.

[9]The results are available on request.

more than changes in unit labour costs. The Marshall–Lerner conditions appear to hold in most sectors, with depreciation improving the trade balance.

This paper has come some way in analysing the relative role of national and international technology-based linkages as a determinant of international market share dynamics. Of course, some important features remain unexplained still. With respect to future empirical work, along with the more detailed analysis of the relative importance of national and international technology-based linkages for different types of countries (such as large and small countries), we suggest some potential improvements, including the use of FDI-related technological linkages, in addition to the use of linkages calculated on the basis of patent citations and/or bibliometric data. While taking advantage of this type of data, the importance of future analyses of the creation and diffusion of pervasive technologies (such as information and communication technologies) for market share dynamics should be underscored.

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Appendix: The variables

Our measure of unit labour costs is defined as follows:

$$ULC_{izjt} = \ln(W_{izt}/VA_{izt}) - \ln(W_{ijt}/VA_{ijt}) \tag{A1}$$

where W_{izt} is the wage sum of country *z*, in sector *i*, at time *t*, expressed in current prices (while W_{ijt} is the same variable for country *j*, i.e. the trade partner of country *z*, and similarly for the other variables), and VA_{izt} is value added in fixed prices.

The exchange rate is defined as follows:

$$EXC_{zjt} = \ln(EXC_{zt}) - \ln(EXC_{jt}) \tag{A2}$$

where EXC_{zt} is the US $ exchange rate of country *z*, at time *t*.

The measure of 'own sector' technological activity can be defined as:

$$PAT_{izjt} = \ln(PAT_{izt}) - \ln(PAT_{ijt}) \tag{A3}$$

where PAT_{izjt} is the number of patents of country *z*, in sector *i*, at time *t*. It should be noted that we apply a three-year moving average for the patenting variable in order to avoid problems of small numbers, in particular with respect to the smaller countries in our sample. The upstream domestic linkage variable can be defined as:

$$UL_{ijt} = \left(\mathbf{y}_{li}^{tz} / \mathbf{Y}_{i}^{tz}\right)\mathbf{RD}_{l}^{tz} \quad \text{for } i \neq l \tag{A4}$$

where $\mathbf{y}^{tz}{}_{li}$ is a vector of the deliveries of intermediates to the sector in question[10] and $\mathbf{Y}^{tz}{}_{i}$ is a vector of total output at time *t* in country *z*. $\mathbf{RD}^{tz}{}_{l}$ is a vector of R&D intensities (R&D on value added), as proxy of the technological competence of these sectors. Thus, the variable measures sector *l*'s importance as a supplier to sector *i*. This variables is also expressed in logarithmic differences from the variable of the trade partner (not

[10]'Rent spillovers' have been calculated in a similar way by Braconier and Sjöholm (1998), using the same input–output tables. They found no effect of such national (nor international) spillovers on productivity.

shown for reasons of simplicity). The foreign linkage variable has been described in the text. The dependent variable is the logarithm of the share of exports of country *z* to country *j* and its imports (i.e. exports of country *j* to country *z*) in current prices and US dollars.

The patent data are taken from the United States Patent and Trademark Office (USPTO). All other data applied are taken from the OECD STAN database (1995 edition). The main limiting factor is the use of the STAN input–output tables, which are only available for nine OECD countries (Australia, Canada, Denmark, France, Germany, the United Kingdom, Japan, The Netherlands, and the United States). Also the input–output data is only available for five points in time (early 1970s, mid-1970s, early 1980s, mid-1980s and 1990). It should be noted that the input–output tables are not exactly from the same year. For instance, the 'mid-1970s' observation is 1974 for Australia, while this observation for Canada was obtained in 1976. Even though the input–output data are not available on a yearly basis, the inclusion allows for the calculation of up- and down-stream 'technology flows', based on 'real' economic transactions. Often, in this kind of study, the intensity of economic transactions between sectors is calculated on the basis of one country. Accordingly, the *intensity* of transactions between sectors of that country is then assumed to be the same in other countries in the analysis, while, for example, the structure of production differs. So this advantage has to be judged against the smaller number of observations, and a number of missing values.

It can be argued that capital goods embody R&D to a larger extent than other types of goods. However, input–output matrices on capital formation suffer from a series of problems, including lack of compatibility between countries and a (very) large number of missing values. Given those serious limitations, we use the matrices available on flows of intermediate products. As pointed out above, the input–output data are only available for five points in time. However, as we would like to estimate our model on a panel data basis, we make a linear point-to-point interpolation of the input–output component of the variable. In this way we apply the input–output observations for the early 1970s and for the mid-1970s—as starting point and end point respectively—over the four years in the period 1973–1976 (the input–output observations for the mid-1970s and the early 1980s to the years 1977–1980; the early 1980s and the mid-1980s to 1981–1984; the mid-1980s and 1990 to 1985–1988; and the input–output observation from 1990 applies to the years 1989–1991).[11] The model used in this paper is estimated for 19 years over the period 1973–1991.

[11]Out of the 45 possible input–output tables, five tables are missing in the OECD data. In those cases we made interpolations of the input–output relations for longer time periods than the 'normal' 3–4 years.