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Abstract:
This paper introduces inter-sectoral technology-based linkages (or technological spillovers) in a empirical model of international market share dynamics. The Pavitt taxonomy is applied as a yardstick for interpreting the empirical results. In accordance with the criteria behind the taxonomy, we find upstream linkages to be more important for the determination of market shares in scale intensive and supplier dominated sectors, while downstream linkages are particularly important for specialised suppliers. We also find investment to be more important for scale intensive types of sectors, formal R&D for science based sectors, and costs for supplier dominated sectors. The results highlight that the relative importance of different sources of competitiveness differs across sectors and thus reconcile the differences in emphasis in relation to the role of technology in determining trade flows, between (a) a tradition that stresses the importance of knowledge developed in a particular sector, and (b) the so-called 'home market hypothesis', that points out how inter-sectoral linkages within a particular country determine trade flows from that country.

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1. INTRODUCTION

This paper introduces technology-based inter-sectoral linkages (or put in a different vocabulary; technological spillovers[1]), in an empirical model of international market share dynamics. While the explanation of market share dynamics has been an important aspiration of a large part of the recent empirical literature on international trade (e.g. Amendola, Dosi and Papagni, 1993; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995; Verspagen and Wakelin, 1997), technological linkages have to the mind of the present authors not so far been incorporated in such a model. In the words of Magnier and Toujas-Bernate:

> Of course, some important features [of market share dynamics] remain largely unexplained. With respect to future empirical work, along with the introduction of other technological accurate variables (granted patents, labor skills, number of researchers, ...), we suggest some potential improvements ... But above all, other country specificities related to the diffusion of technology between industrial sectors in each country should be underscored. (Magnier and Toujas-Bernate, 1994, p. 516, our insert in square brackets).

That linkages or spillovers should matter in this context can be derived from a number of types of theoretical literature, including neoclassical approaches (e.g. Grossman and Helpman, 1991), but also from evolutionary approaches such as Verspagen (1993). In addition it is clear that since the idea of (national) inter-sectoral linkages underlies theories of national systems of innovation as a generic foundation (Lundvall, 1992), the findings of the paper have important implications for how theories of national systems of innovation should be confined, as such linkages might not be equally important across industrial sectors.

The set-up of the model, used in this paper, is similar to the dynamic model developed by Amendola *et al.* (1993), although we estimate a model at the sectoral level, as opposed to the (country) aggregate model 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. Accordingly, the estimations carried out in this paper aim at explaining market share dynamics by means of unit labour costs (as a reflection of production costs), investment (an indicator of scale requirements and a proxy for embodied technology), R&D statistics (an indicator of the

1. The differences and similarities between technological linkages and spillovers are discussed later in the paper (Section 2.2).

technological development), and we then add a variable similar to the linkage variable constructed by Laursen and Drejer (forthcoming, 1999), in order to see whether such linkages (or national spillovers) matter for gaining or losing market shares, over time.

At the same time it is the idea of the paper to make an attempt to reconcile the different views on which dimension of technological development is the most important one, in determining trade flows between countries. In this context some theorists have argued that because of ‘knowledge stickiness’, knowledge developed in a particular sector and country would induce trade flows from that country. In contrast, the proponents of the so-called ‘home market hypothesis’ have emphasised another aspect of technology in arguing that particularly strong inter-sectoral linkages within a particular country, determine trade flows from that country. By adopting a sectoral approach to this issue, it is the aim of the paper to draw conclusions concerning the extent to which the two types of explanations are in fact complementary, rather than substitutes.

2. THEORIES OF INTERNATIONAL TRADE

A general starting point of this paper is a ‘technology gap’ approach to explaining trade flows. In this way we adopt the Ricardian explanation of trade flows as resting on differences in labour productivity between countries. Ricardo originally ascribed the differences in labour productivity to climate and other factors related to agricultural production, as well as to a relative immobility of capital. This paper explores a range of other possible reasons for differences in labour productivity all sharing a common relation to the technological levels of the countries. In this context Section 2.1 discusses the importance of cumulativeness in technological change; while Section 2.2 focuses on the role of technology-based inter-sectoral linkages (the so-called home market effect) and spillovers in explaining trade flows.

2.1. The direct importance of technology for trade

Under the label of ‘technology gap theory’ Posner (1961) introduced the idea that temporary monopoly profits can be appropriated, based on a technological lead, in an international trade context. Given the assumption that technology is not a free and universally available good, Posner argued that while technology might be important for trade in some sectors, and not in others, innovations made in one country (in technology intensive sectors) would benefit that country as long as the lead could be kept. That is, a country will have ample first-mover advantages in a given sector, until other countries have imitated the innovation. In the words of Posner:

> … the development of new products does not occur simultaneously in all countries – in most cases the only reason they are introduced is because the entrepreneur concerned is hoping to achieve a quasi-monopoly for a period of time. During this period of time a cause of trade exists which is independent of any previously existing comparative cost differences (Posner, 1961, pp. 323-324).

Hence, in the original formulation of Posner, once imitation has taken place, more traditional factors of adjustment and specialisation would take over and determine trade flows. However, as argued by Dosi and Soete (1988), there is not necessarily anything impermanent about the importance of technology in determining trade flows, since static and dynamic scale economies flowing from the initial break-through acts to prolong the lead. Coupled with new product innovations, these scale economies might well secure a continuous trade flow. Metcalfe and Soete (1984) also observe that trade can be due to the difference between national rates of diffusion of demand and capacity growth and to time lags in technology transfer with respect both to demand and production. While this type of trade should be transitory it is possible that different diffusion patterns may result in different patterns of development within a technology thus affecting countries' long-run comparative advantages.

A formalised neoclassical treatment of the idea is found in Krugman (1985). In the model technology differs between (two) countries in terms of level, but also goods can be ranked by technology-intensity. The trade pattern reflects an interaction between countries and goods; technologically advanced countries have a comparative advantage in technology-intensive goods (but an absolute advantage in all sectors). One of the outcomes of the model is that technical progress in an advanced country, which widens the technological gap, opens up greater opportunity to trade, which in turn raises real income levels in both countries, whereas 'catch up' by a follower tends to hurt the leader by elimination of gains from trade.

In 'evolutionary' ('technology gap') literature on international trade (Dosi, Pavitt and Soete, 1990; Verspagen, 1993; Dosi, Fabiani, Aversi and Meacci, 1994) international trade specialisation is the outcome of country- and sector-specific (technological) learning processes. In evolutionary theory the mechanism of transmission secures a certain level of stability of trade specialisation, because of limited computational capabilities of the agents in question and because of fundamental uncertainty in the process of innovation. Given bounded rationality and fundamental uncertainty, firms (and hence countries) will try to diversify their technology by searching in zones that enable them to build on the firms existing technology base. In other words trade patterns are firstly likely to be stable and secondly, changes in the patterns are likely to be rooted in previous activities of the firms of a particular country.

Overall studies using the technology-gap approach to trade emphasise inter-country differences in technical change as the basis of international trade flows. In this framework it is variation across countries in innovation capabilities within each sector, rather than inter-industry differences in endowments, which matters in explaining the direction of trade.

From an empirical point of view, the technology gap theory has gained support from Soete (1981) and Dosi *et al.* (1990). Based on cross-country regression analysis, for a single year, these two studies showed that among 40 sectors about half of these were found to be influenced in their direction by technological specialisation (measured as US patents) in the same sector. From a panel data perspective, in a dynamic setting - in an aggregate country perspective - Amendola *et al.* (1993) found convincing support for the hypothesis as well. Also applying panel data - and from a sectoral as well as a country-wise perspective - Amable and Verspagen (1995) showed that competitiveness in trade was significantly influenced by technological capabilities (US patenting) in eleven out of the eighteen sectors in question, when using a dynamic specification of the model.

2.2. The ‘home market effect’

The importance of domestic linkages (the ‘home-market effect’) in a trade theory context, was suggested by the Swedish economist Burenstam Linder (1961). The basic idea is that a country’s domestic market may act as a protected environment for new products, before exports to foreign markets are initiated. Nevertheless, it should be pointed out that the idea that inter-sectoral linkages in the domestic economy have an impact on competitiveness has its most important roots in development economics. In this context Hirschman (1958) distinguishes between backward and forward linkages. Backward linkage effects are related to derived demand, i.e. the provision of input for a given activity. Forward linkage effects[2] are related to output-utilisation, i.e. the outputs from a given activity will induce attempts to use this output as inputs in some new activities (Hirschman, 1958, p. 100).

Extending the model due to Linder, Raymond Vernon (1966) introduced the product-life

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2. In the empirical part of the paper we are going to apply the term ‘downstream linkage’, as the label for what is known as a ‘forward linkage’ in the linkage literature.

cycle model in which (labour saving) innovation is first created in the most advanced countries, and subsequently diffuses to lesser and lesser advanced countries. According to Vernon geographical proximity is conducive to innovation because of the ease of communication over short distances:

> There is good reason to believe, however, that the entrepreneur's consciousness of and responsiveness to opportunity are a function of ease of communication; and further, that ease of communication is a function of geographical proximity. Accordingly, we abandon the powerful simplifying notion that knowledge is a universal good, and introduce it as an independent variable in the decision to trade and invest. The fact that the search for knowledge is an inseparable part of the decision making process and that the relative ease of access to knowledge can profoundly affect the outcome are now reasonably well established through empirical research. One implication of that fact is that producers in any market are more likely to be aware of the opportunity to introduce new products in *that* market than producers located elsewhere would be. (Vernon, 1966, p. 192, our italics).

The Linder-Vernon hypothesis has further been developed by Lundvall (1988) by means of the idea of the *organised market*, which involves close interaction between sellers and buyers as a fertile environment for innovation. The interaction may take the form of mutual exchange of information, but may also involve direct co-operation between users and producers of technology. Two properties of the user-producer relationship are important in a 'home market' context. Firstly, because it is time-consuming and costly to develop efficient channels of communication and codes of conduct (often tacit) between users and producers, the relationships are likely to be durable and selective. Secondly, when technology is sophisticated and changing rapidly, proximity in terms of space and culture is seen to be conducive to innovation and thereby to competitiveness (1988, p.355). Thus, such localised and durable linkages give rise to dynamic increasing returns at the level of the country (or region), as transactions costs are seen to be lower in the national context. Hence a stable user-producer relationship may be seen as an institution that reduces the costs of innovation, while at the same time making it easier to appropriate the economic benefits from the innovation.

One possible interpretation of the Linder-Vernon hypothesis has been formalised by Krugman (1980). The model is based on imperfect competition, and allows for economies of scale and transportation costs. In a two country, two industry setting the model demonstrates that when the two countries trade, each will be specialising (although not necessarily perfect specialisation, depending on the relative importance of transportation costs vis á vis economies of scale) in the industry for whose products it has the *relatively* larger demand. The reason for this is that there will be an incentive to concentrate the production of a good near its largest market, in order to reap economies of scale, while minimising transportation costs.

However, it should be noted that both Linder and Vernon were primarily concerned with the quality of demand, rather than the mere size of demand. In other words, the original formulation made by Linder (and Vernon) concerned the conditions for learning on the (national) home-market.

(Upstream) linkages might also be interpreted as localised 'spillovers'. The public good aspect of technology has recently been recognised in economics, in particular in the field of new growth theory (see e.g. Barro and Sala-i-Martin, 1995). Technology developed by one firm can be used at cost typically lower than the original cost of development. In addition, knowledge developed by one firm can be seen to enhance the productivity of producing knowledge by other firms, as the knowledge can be 'built on' by the other firms, when they produce new knowledge themselves.

In their book on innovation and growth in an international context, Grossman and Helpman (1991) examine the impact of international and national spillovers on trade specialisation and trade flows in a two-country, two sector model. The sectors differ in the technological opportunities offered in terms of a homogeneous product vs. a horizontally differentiated product; the latter exhibiting increasing returns at the sectoral level, as low costs of developing a new variety is a function of the level of knowledge already created. In the model allowing only for pure international spillovers, the pattern of trade is solely determined by the relative factor endowments of the countries (human capital vis-á-vis labour abundant countries), and the initial level of R&D is found to have no effect on comparative advantage; the rate of innovation; nor on the growth rate of the country. In contrast, if spillovers are assumed to be only national in scope the conclusion is that the initial conditions – all other things being equal – turn out to be crucial. That is, if a country begins with a head start in the accumulation of knowledge, that country widens it productivity lead over time. Then the country becomes increasingly the exporter of the horizontally differentiated product.

From an evolutionary point of view (using a non-linear framework), but inspired by the post-Keynesian Dixon-Thirlwall model (1975), Verspagen (1993) constructs a one sector, two country model (a technologically advanced 'North' and a technologically backward 'South') of export-based growth, assuming that technological capabilities differ between countries not only in the ability to produce new knowledge, but also in the ability to imitate knowledge developed elsewhere. The outcome of the model is that the combination of the initial size of the technological gap between the countries and the intrinsic ability to assimilate knowledge spillovers (by the 'South') determines whether a country can catch up, relative to the technological leader, or whether it will fall behind.

Before discussing the differences and similarities between technological linkages and technological spillovers and between the 'home market hypothesis' and the spillover literature, 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.[3] 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 particularly related to input purchase flows.

While rent-spillovers are difficult to distinguish empirically from technological linkages (as they both involve inter-industry transactions), in our view the main conceptual difference between them is, on one hand, the fact that technological linkages do necessarily involve the existence of externalities, and on the other, that they are consistent with a two-way interaction between sectors rather than involving the one-way transfer of technology from one sector to another.

The argument concerning rent-spillovers is that when commodities flow freely across sectors, the firms of a sector in question have access to the R&D stock of all sectors (in an extreme case - where all sectors' outputs are equally 'relevant' to each other), because independently of in which sector an input has been developed or improved, the firms of any sector can purchase the input and employ it in manufacturing (cf. Coe and Helpman, 1995). Hence, in comparison with the idea of rent-spillovers, the 'home market hypothesis' is a more dynamic argument, in the sense that the focus is on how *new* technologies and products are created, in terms of exchange of information between suppliers and users of a product, rather than on diffusion issues, as is dealt with in the case of rent-spillovers. Nevertheless, as real

3. It should be pointed out that rent spillovers are mainly related to the market structure in the technology producing industry, rather than being true externalities in the strict sense of the word (Griliches, 1979; Verspagen, 1997).

knowledge spillovers are the ideas borrowed by the research teams of industry *i* from the research results of industry *j*, one can argue that home market linkages are a particular kind of knowledge spillovers, related to input purchase flows (Los, 1996).

Other differences between the literature on spillovers and the ‘home market hypothesis’ are that the aim of a large part of the now large (mainly empirical) spillover literature (for important recent contributions, see Coe and Helpman, 1995; Verspagen, 1997), is to estimate the effect of technological spillovers on productivity, while the aim of the ‘home market hypothesis’ is to give an explanation for international trade specialisation. Moreover in the ‘home market hypothesis’ particular importance is given to domestic demand and the role of customers while demand does not play a substantial role in the literature on technological spillovers. It should also be pointed out that spillovers can be both national or international in scope, whereas home market linkages are localised (national) per definition.

In this paper we are going to apply an input-output measure of linkages. In the spillover literature, the input-output measure would be equivalent to rent-spillovers. Our empirical analysis aims at assessing the importance of the technological capabilities of upstream and downstream sectors in affecting export shares of a particular sector irrespective on whether these linkages might be interpreted as evidence of spillovers.

It is also worth noting that the qualitative mechanisms, discussed by Linder, Vernon and Lundvall are hard to measure *per se.* In fact, the interaction as described by both authors, need not necessarily be large, as reflected in exchange of commodities between firms situated in different sectors. However, we assume in this paper, that the quantity of useful information will on average, be related to the quantity of commodities exchanged.

Empirically, the home market hypothesis has gained some support at the descriptive level by Andersen *et al.* (1981) and econometrically by Fagerberg (1992; 1995). However the tests conducted by Fagerberg only applies one variable reflecting a ‘backward spillover’, and is not based on data on economic transactions. Instead the independent variable is the trade specialisation (Balassa figure) of a country in an ‘upstream sector’ with respect to the dependent variable (also measured as Balassa). This paper will apply data on actual economic transactions (I-O data) used as weights (see Section 3.1 below) on the technological output from upstream or downstream sectors with respect to the sector to be explained.

2.3. The Pavitt-taxonomy in a trade context

Given that the principal sources of technological change (inducement mechanisms) differ between firms according to principal sector of activity, different explanations for trade should not be expected to be of equal importance across industrial sectors. Thus, if trade specialisation is determined to a large extent by technology, we should not expect the importance of 'technology' to appear along the same dimensions.

Pavitt (1984), identifies differences in the importance of different sources of innovation according to which broad sector the individual firm belongs. The taxonomy of firms, according to principal activity, emerged out of a statistical analysis of more than 2000 post-war innovations in Britain and was explained by the sources of technology; the nature of users needs; and means of appropriation. Four types of firms were identified accordingly, namely supplier dominated firms, scale-intensive firms, specialised suppliers and science-based firms. *Supplier dominated* firms are typically small and found in manufacturing and non-manufacturing sectors. Most technology comes from suppliers of equipment and material. *Scale intensive* firms are found in bulk materials and assembly. Their internal sources of technology are production engineering and R&D departments. External sources of technology include mainly interactive learning with specialised suppliers, but also inputs from science-based firms are of some importance. *Specialised suppliers* are small firms, which are producers of production equipment and control instrumentation. Their main internal sources are primarily design and development. External sources are users (science-based and scale-intensive firms). *Science based firms* are found in the chemical and electronic sectors. Their main internal sources of technology are internal R&D and production engineering. Important external sources of technology include universities, but also specialised suppliers.

Even though the taxonomy was devised at the level of the firm, it has implications at the level of the industry, as we would expect the broad sectoral regularities of firms to be reflected in the aggregate behaviour of the sector. Thus, given the above description of the taxonomy, one would expect internal R&D to be most important for gaining market shares in science based sectors, while upstream and downstream linkages should be expected to be more important in the case of specialised suppliers. For scale intensive sectors, investment and inter-sectoral linkages - but also to some extent R&D - should be of importance, while supplier dominated sectors should to some extent be expected to be determined by investment, upstream linkages and by low unit labour costs. But as we are dealing with sectors of traditional manufacturing in this case, more traditional factors (resource endowments) might be particularly important for these sectors.

The Pavitt taxonomy has been criticised on a number of points, including a set of criticisms relating to the fact the sectoral boundaries are not always straight forward. That is, firms (and sectors) cannot always easily be uniquely defined as one of the four Pavitt type firms. Some firms (and sectors) may have such attributes, so that they can be said to be affiliated to more than one of the Pavitt-type sectors. It should be stressed however, that while the Pavitt taxonomy has held up reasonably well in subsequent empirical tests (Cesaratto and Mangano, 1992; Arundel, van de Paal and Soete, 1995), it inevitable simplifies.

Using the Pavitt taxonomy as a starting point, this paper statistically investigates the importance of variables reflecting different inducement mechanisms for trade flows over 19 years, in 19 manufacturing sectors (see the Appendix for a description of the sectors), across 9 OECD countries.

3. EMPIRICAL ANALYSIS

3.1. The variables

In most empirical analyses on the determinants of export shares, cost and technological competitiveness have been identified as the major explanatory variables (Soete, 1981; Greenhalgh, Taylor and Wilson, 1994; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995; Meliciani and Piermartini, 1997; Carlin, Glynn and Reenen, 1998).

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. Our measure is defined as follows:

$$ULC_{ijt} = ln(W^{c}_{ijt} / VA^{f}_{ijt}) - ln((\sum_{j}(W^{c}_{ijt} / VA^{f}_{ijt})(1/n))$$

where W^{c}_{ijt} is the wage sum of country *j*, in sector *i*, and time *t*, expressed in current prices and *VA* is value added in fixed prices; *n* is the number of countries (for each sector and time).

Different papers have used different proxies in order to measure technological competitiveness. The most used measures of disembodied technology are R&D expenditures and patent statistics: the former is better suited to capture the inputs to the innovation process while the second is a measure of the output. In this paper we use R&D expenditures because there are better suited to capture the formal innovation activity in science based firms. Moreover we prefer to measure technological linkages on the basis of R&D since they can also be interpreted as knowledge spillovers. In order to correct for the size of the country we divide our measure by population:

$$RDS_{ijt} = ln(RD^{f}_{ijt} \,/\, (\sum_{j} RD^{f}_{ijt} \,/\, n)(1 \,/\, pop_{jt}))$$

where RD^{f}_{ijt} is the R&D expenditure of country *j*, in sector *i*, and time *t*, expressed in constant prices and pop_{jt} is the population of country *j* at time *t*. Embodied technical change is measured by investment also in fixed prices and divided by population (*IN)*. The dependent variable is export market shares in fixed prices divided by population (*MS*).

The downstream linkage variable can be defined as:

$$DL_{ijt} = (\mathbf{y}^{tj}_{iz} \,/\, \mathbf{Y}^{tj}_{i})\mathbf{RD}^{tj}_{z} \;\; for\ i \neq z,$$

where $\mathbf{y}^{tj}_{iz}$ is a vector of deliveries of intermediates from the sector in question (sector *i*) to the other sectors (sector *z*) and $\mathbf{Y}^{tj}_{i}$ is a vector of total output at time *t* in country *j*. $\mathbf{RD}^{tj}_{z}$ is a vector of R&D expressed in fixed prices (normalised for country-size, by dividing by the total population size of country *j*, at time *t*), as proxy of the technological competence of these sectors. In other words the variable measures sector *z*’s importance as a user of sector *i*’s output. Likewise for the upstream linkage variable:

$$UL_{ijt} = (\mathbf{y}^{tj}_{zi} \,/\, \mathbf{Y}^{tj}_{i})\mathbf{RD}^{tj}_{z} \;\; for\ i \neq z,$$

where $\mathbf{y}^{tj}_{zi}$ is a vector of the deliveries of intermediates to the sector in question. Thus, the variable measures sector *z*’s importance as a supplier to sector *i*. As with the other variables the linkage variables are expressed in logarithmic differences from the country mean at any given time and sector (not shown for reasons of simplicity).

Population data are taken from OECD Economic Outlook and Reference Supplement (No. 59). 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, Great Britain, 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 I-O 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 inclusion of I-O data reduces the amount of observations, 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, are 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 e.g. the structure of production differs. So this advantage has to be judged against the smaller number of observations, and a number of missing values.

As pointed out above, the I-O data is only available for five points in time. However, as we would like to estimate our model on a panel data basis, we assume that the structures (the I-O relations) of the economies remain the same over 3-4 year periods. In this way we apply the single I-O observation for the early 1970s four times, for each of the four years in the period 1973-1976 (the mid 1970s I-O observation applies to the years 1977-1980; the early 1980s to 1981-1984; the mid 1980s to 1985-1988; and the I-O observation from 1990 applies to the years 1989-1991). While we assume that the I-O component of the linkage variable remains the same over 3-4 year periods, we apply the R&D component on a yearly basis. Hence, seen in its total, the variable does not remain constant, over the 3-4 year period. The model applied in this paper is estimated for 19 years over the period 1973-1991.

3.2. Econometric method

In order to reduce the probability of estimating spurious regression while, at the same time, maintaining information on the long-run impact of different factors of competitiveness on export shares, we estimate a dynamic specification with a lagged dependent variable. Considering that there is consensus in trade literature about persistence in countries' export market shares (Dixit, 1989; Amendola *et al.*, 1993; Giovannetti and Samiei, 1996) this approach is preferred to other dynamic specifications that estimate adjustment equations (Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995) because it directly allows for persistence. Moreover it allows to compare short and long-run effects of the independent variables on market shares.

Adopting the autoreggresive representation on the variables defined in Section 3.1 we obtain:

$$MS_{ijt}=\alpha_1 MS_{ijt-1}+ \alpha_2 RDS_{ijt}+ \alpha_3 ULC_{ijt}+ \alpha_4 IN_{ijt}+ \alpha_5 UL_{ijt}+\alpha_6 DL_{ijt}+\alpha_{7i}+\alpha_{8j}+e_{ijt} \qquad (1)$$

where α_{6i} is a sector-specific effect, α_{7j} is a country-specific effect, e_{ijt} is the error term and all other variables were described in the section above.

This specification allows to obtain only indirect estimates of long-run multipliers, in order to obtain direct estimates we can reformulate Equation *(1)* as follows:

$$MS_{ijt}=\beta_1(MS_{ij} - MS_{ijt-1})+\beta_2 RDS_{ijt}+ \beta_3 ULC_{ijt}+ \beta_4 IN_{ijt}+ \beta_5 UL_{ijt}+\beta_6 DL_{ijt}+ \beta_{7i}+\beta_{8j} +u_{ijt}$$

where $\beta_1=-\alpha_1/(1-\alpha_1)$, $u=e/(1-\alpha_1)$ and $\beta_i=\alpha_i/(1-\alpha_1)$ with i=2,3,4,5,6,7,8. In this equation, which can be obtained by deducting $\alpha_1 MS_{ijt}$ from each side of Equation (1), the coefficients on the independent variables are the long-run multipliers.

3.3. Sectoral affiliation and expectations

Each of the 19 sectors have been assigned to the four Pavitt sectors. The classification is shown in the Appendix. However, since any such assignment is somewhat arbitrary on the boundaries, the chosen classification deserves some comments. First of all, the classification, according to the Pavitt taxonomy, used in this paper follows to a large extent OECD (1992), and differ only from this in the case of ‘food, drink and tobacco’; ‘industrial chemicals’; ‘instruments’ and ‘fabricated metal products’. In the three first cases, the sectors are on the boundaries of the ‘Pavitt sectors’. Firms in the ‘food, drink and tobacco’ sector possess both scale intensive characteristics, but also some supplier dominated characteristics, firms in the ‘industrial chemicals’ sector possess both science based characteristics, but also some scale intensive characteristics, and firms in the instruments sector both carry specialised supplier characteristics, but also some science based characteristics. In all cases we opted for the original Pavitt classification, as scale intensive, science based and specialised suppliers respectively. If one look at the ISIC nomenclature, under ‘fabricated metal products’, it can be seen that this sector produces mainly standard products (nails, screws, steelwire etc.). In contrast to the OECD, we argue that this type of production is not mainly carried out by specialised supplier firms.

The *a priori* reasons for including ‘petroleum refineries’ as a supplier dominated sector, even though the firms in these sectors are probably to some extent scale intensive, is that we are dealing with national specialisation. Thus the specialisation in these sectors is to some extent determined by what goes on in the (related) primary sectors, which in turn are supplier dominated, in addition to being influenced by natural resource availability. As other sectors on the boundary should be mentioned non-ferrous metals (classified as supplier dominated, but could be classified as scale intensive) and electrical machinery (classified as specialised suppliers, but has some science based properties).

To recapitulate from the above description of the Pavitt taxonomy, we expect internal R&D to be most important for competitiveness in science based sectors, while upstream and downstream linkages is expected to be more important in the case of specialised suppliers. For scale intensive sectors, investment and inter-sectoral linkages - but also to some extent R&D - should be of importance, while exports in supplier dominated sectors is expected to depend on low unit labour costs, high investment and by upstream linkages.

In general we expect all parameters to have a positive sign, but the parameter for unit labour costs.

3.4. Estimation

Table 1 reports the results of the estimation for each of the four Pavitt's sectors. Due to problems of multicollinearity we could not include the upstream and downstream linkage variables in the same regression therefore we report two sets of results (i) and (ii) with respectively upstream and downstream linkages. Moreover the dynamic specification allows to estimate both the long-run and the short-run impact of each variable; the first is referred to as β in Table 1 and the second as α.

Overall the results appear to be consistent with our expectations on the relative importance of the different factors of competitiveness in the different sectors. In particular the formal activity of R&D appears to play the largest role in science based industries, unit labour costs in supplier dominated industries, investment in scale intensive, the upstream linkage variable in scale intensive and the downstream linkage variable in supplier dominated.

While the relative importance of the different factors of competitiveness is largely consistent with what could be expected from the characteristics of the sectors, it is worth observing that R&D, costs and linkages play an important role in affecting export shares in almost all sectors both in the short and in the long-run. In particular the formal activity of R&D affects export shares not only in science based industries but also in supplier

Table 1: *Regression Results*

	Supplier dominated				***Science based***				***Scale intensive***				***Specialised suppliers***			
	Model (i)		*Model (ii)*		*Model (i)*		*Model (ii)*		*Model (i)*		*Model (ii)*		*Model (i)*		*Model (ii)*	
	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α
Investment																
Coefficient	0.76	0.03	0.87	0.04	0.65	0.03	0.90	0.04	0.94	0.04	1.04	0.05	0.71	0.03	0.86	0.04
t-value	1.83	1.83	1.98	1.99	1.40	1.39	1.76	1.78	3.33	3.21	3.43	3.37	1.15	1.15	1.32	1.33
Unit labour costs																
Coefficient	-5.10	-0.23	-5.53	-0.24	-1.48	-0.07	-1.73	-0.08	-4.11	-0.19	-4.20	-0.18	-0.69	-0.03	-0.36	-0.02
t-value	-4.35	-8.30	-4.20	-8.49	-2.42	-2.60	-2.60	-2.89	-4.37	-7.05	-4.20	-6.81	-0.69	-0.69	-0.35	-0.34
R&D																
Coefficient	0.41	0.02	0.35	0.01	1.32	0.06	1.22	0.05	0.17	0.01	0.19	0.01	0.99	0.05	1.02	0.04
t-value	2.13	2.26	1.76	1.83	3.21	3.44	2.90	3.05	1.92	1.93	2.00	2.02	1.82	1.86	1.90	1.96
Upstream linkages																
Coefficient	1.67	0.08			1.55	0.07			2.05	0.09			1.95	0.09		
t-value	3.06	3.96			3.37	4.18			4.19	6.04			2.95	3.28		
Downstream linkages																
Coefficient			1.05	0.05			0.62	0.03			0.94	0.04			1.12	0.05
t-value			2.15	2.49			1.83	1.92			3.00	3.52			2.12	2.21
	Model (i)	*Model (ii)*														
Adjusted R-squared	0.95	0.94														
Durbin-Watson	1.19	1.18														

Notes: Critical values are 2.58, 1.96, 1.64 at 1%, 5% and 10% levels of significance respectively; α is the short-run estimate and β is the long-run estimate. Country and sectoral fixed effects not printed for reasons of space.

dominated, scale intensive and specialised suppliers. While the importance of R&D in scale intensive and specialised suppliers is not surprising considering that some ‘medium-tech’ sectors are included in the categories (e.g. plastic and electrical machinery), its role in supplier dominated sectors shows the growing importance of investment in R&D also in traditional industries.

Cost variables play the major role in supplier dominated sectors but are significant also in science based and scale intensive industries. This result differs from those of Amendola *et al*. (1993), but we have to consider that their dependent variable is export shares in current prices and we expect unit labour costs to affect negatively export quantities but positively export prices.

Investment is significant in scale intensive and in supplier dominated industries consistently with the view that these industries acquire a large share of their technology through the purchase of capital goods.

As far as the linkage variables are concerned, they appear to play an important role in affecting export shares. The upstream linkage variable is highly significant in all Pavitt's sectors with the largest impact in scale intensive, followed by specialised suppliers, supplier dominated and science based. This is consistent with the Pavitt representation of the main technological linkages (Pavitt, 1984, p. 364) amongst the different sectors where, through the purchase of goods embodying technology, scale intensive firms receive technology from science based firms and specialised suppliers (e.g. the use of electronics and chemistry from the former and the use of equipment and instrumentation from the latter); supplier-dominated firms receive technology from both scale intensive and science based firms (e.g. the use of power tools, metals and transport equipment from the former and of consumer electronics from the latter); and specialised suppliers receive technology from science-based firms as well.

Also downstream linkages appear to be significant in all sectors with the largest impact in specialised suppliers followed by supplier dominated, scale intensive and science based industries. The largest impact in specialised suppliers is what we expect from the Pavitt's taxonomy where the main focus of firms' innovative activities in these industries is the production of product innovations for use in other sectors and therefore firms in a wide range of user sectors contribute to their innovative performance.

Overall these results show the important role played by the interaction between different sectors. These interactions have been described here in terms of transactions involving the purchase and sale of goods embodying technology, but the importance of R&D performed in upstream and downstream sectors, for export shares within a sector, is also consistent with the existence of knowledge spillovers, i.e. flows of information across sectors.

4. CONCLUSIONS

This paper has explored the role of inter-sectoral linkages (or spillovers) in generating innovation and thus affecting export shares. We have found that R&D imported from other sectors through both upstream and downstream linkages has a significant positive effect on international competitiveness.

Another important result of the paper is that the relative importance of the determinants of export shares varies across sectors. In particular the formal activity of R&D plays a major role in science based industries; costs, technology acquired through capital goods and imported from upstream sectors are particularly important in supplier dominated industries; investment and upstream linkages are also highly significant in scale intensive industries;

while downstream linkages have the largest impact for specialised suppliers. This evidence is consistent with the Pavitt taxonomy on the different sources of innovation across firms.

The results of this paper reconcile the different views on which dimension of technological development is the most important one in determining trade flows between countries. By showing that both direct technological effort and technological linkages are important in determining export shares and that their relative importance varies across sectors, our results are consistent with both the tradition that stresses the importance of knowledge developed in a particular sector for trade flows, and with the so-called ‘home market hypothesis’ that points out how inter-sectoral linkages within a particular country determine trade flows from that country. In terms of policy implications the results also suggest the importance of sectoral-specific technology policies that take into account the relative importance of the different sources of innovation across sectors.

The significant role played by both downstream and upstream linkages suggests that a close interaction between sellers and buyers, both in terms of exchange of information and direct co-operation between users and producers of technology, is a fertile environment for innovation. This idea is central to the ‘home market hypothesis’ and to the concept of national systems of innovation (Lundvall, 1992). However, it should also be pointed out that while inter-sectoral linkages were found to matter for competitiveness in all Pavitt-sectors, such linkages did not matter equally for all sectors. In contrast, the low parameter for downstream linkages in science-based sectors (about half the size of the parameter for specialised suppliers, in the long-run) confirms the findings of Klevorick (1995) and Laursen (1996), concluding that inter-sectoral linkages do no not seem to be of critical importance for science-based sectors more generally, and for pharmaceuticals in particular. In relation to theories of national systems of innovation we believe that research in the field will gain from moving away from generic determinants of performance towards looking at several aspects of technological development (as done in a stylised way in this paper). Second, we believe that the field should aim at increasingly producing empirically testable hypotheses focussing in on the level and the character of the relevant knowledge flows in the system in question.

As we have already pointed out, technological linkages (in particular upstream linkages) are difficult to distinguish from technological spillovers, therefore our results are also consistent with theoretical models that have stressed the importance of spillovers for international competitiveness (Grossman and Helpman, 1991; Verspagen, 1993).

Many theories of international competitiveness have also analysed the impact of competitiveness on economic growth (through the balance-of-payments constraint or/and the type of specialisation). Since economic growth, rather than export shares *per se*, is what matters for improving the standard of living within a country, further empirical investigations could look at the role played by technology and technological linkages on growth in real output across sectors both directly and through their effects on international competitiveness.

Appendix: Sectors used in the analysis and compared to other studies applying the Pavitt taxonomy

		This paper	Pavitt (1984)	Amable and Verspagen (1995)	OECD	Laursen and Drejer (1999)
1	Food, drink and tobacco	SCAI	SCAI	SDOM	SDOM	SDOM
2	Textiles, footwear and leather	SDOM	SDOM	SDOM	SDOM	SDOM
3	Industrial chemicals	SCIB	SCIB	SCIB	SCAI	SCIB
4	Pharmaceuticals	SCIB	SCIB	SCIB	SCIB	SCIB
5	Petroleum refineries	SDOM	-	-	SDOM	SDOM
6	Rubber and plastics	SCAI	-	PROD	SCAI	SCAI
7	Stone, clay and glass	SCAI	SCAI	PROD	SCAI	SCAI
8	Ferrous metals	SCAI	SCAI	PROD	SCAI	SCAI
9	Non-ferrous metals	SDOM	SCAI	PROD	SDOM	SDOM
10	Fabricated metal products	SCAI	SCAI	PROD	SDOM	SCAI
11	Non-electrical machinery	SPEC	SPEC	PROD	SPEC	SPEC
12	Office machines and computers	SCIB	SCIB	SCIB	SCIB	SCIB
13	Electrical machinery	SPEC	SPEC	SCIB	SPEC	SPEC
14	Communic. eq. and semiconductors	SCIB	SCIB	SCIB	SCIB	SCIB
15	Shipbuilding	SCAI	SCAI	PROD	SCAI	SCAI
16	Other transport	SCAI	-	PROD	SCAI	SCAI
17	Motor vehicles	SCAI	SCAI	PROD	SCAI	SCAI
18	Aerospace	SCAI	-	SCIB	-	SCIB
19	Instruments	SPEC	SPEC	PROD	SCIB	SPEC

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Danish **R**esearch **U**nit for **I**ndustrial **D**ynamics

The Research Programme

The DRUID-research programme is organised in 3 different research themes:

- The firm as a learning organisation
- Competence building and inter-firm dynamics
- The learning economy and the competitiveness of systems of innovation

In each of the three areas there is one strategic theoretical and one central empirical and policy oriented orientation.

Theme A: The firm as a learning organisation

The theoretical perspective confronts and combines the resource-based view (Penrose, 1959) with recent approaches where the focus is on learning and the dynamic capabilities of the firm (Dosi, Teece and Winter, 1992). The aim of this theoretical work is to develop an analytical understanding of the firm as a learning organisation.

The empirical and policy issues relate to the nexus technology, productivity, organisational change and human resources. More insight in the dynamic interplay between these factors at the level of the firm is crucial to understand international differences in performance at the macro level in terms of economic growth and employment.

Theme B: Competence building and inter-firm dynamics

The theoretical perspective relates to the dynamics of the inter-firm division of labour and the formation of network relationships between firms. An attempt will be made to develop evolutionary models with Schumpeterian innovations as the motor driving a Marshallian evolution of the division of labour.

The empirical and policy issues relate the formation of knowledge-intensive regional and sectoral networks of firms to competitiveness and structural change. Data on the structure of production will be combined with indicators of knowledge and learning. IO-matrixes which include flows of knowledge and new technologies will be developed and supplemented by data from case-studies and questionnaires.

Theme C: The learning economy and the competitiveness of systems of innovation.

The third theme aims at a stronger conceptual and theoretical base for new concepts such as 'systems of innovation' and 'the learning economy' and to link these concepts to the ecological dimension. The focus is on the interaction between institutional and technical change in a specified geographical space. An attempt will be made to synthesise theories of economic development emphasising the role of science based-sectors with those emphasising learning-by-producing and the growing knowledge-intensity of all economic activities.

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