

# Sectoral patterns of technological activity and export market share dynamics

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This paper focuses on a selected number of OECD countries and manufacturing sectors and shows the importance of sectoral diversity in the innovative process and in the relation between technology and world market share dynamics. The econometric exercise confirms the importance of technological variables in the relation with world market shares in two ways: first they are, in general, statistically significant, second the taxonomy of technological classes in terms of R&D intensity seems to be meaningful in disentangling the role played by sectoral diversity in the relation between embodied and disembodied investment and competitiveness. Sectoral diversity emerges in the statistical significance of the coefficients and in the time lag structure. Moreover, the values of estimated R&D parameters are correlated with the sectoral R&D intensity.

*Key words:* Innovation, Technical change, Exports, Competitiveness

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## 1. Introduction

This paper is an attempt to explore empirically the links between two groups of studies. The first group of studies emphasises the role of technological diversity and tries to map industrial specificity (in terms of technological knowledge bases, technological opportunities and incentives to innovation) into regular patterns of innovative activity and firm behaviour (Pavitt, 1984; Dosi, 1988; Levin, 1988; Patel and Pavitt, 1994; Malerba and Orsenigo, 1995, 1997; Breschi *et al.*, 2000). The second group draws on the technological gap tradition and shows the mechanisms by which technology and firms' innovative activity explain the variance in countries' export performance (Soete, 1981; Fagerberg, 1988; Dosi *et al.* 1990; Amendola *et al.*, 1993; Amable and Verspagen, 1995).

This paper focuses on the nature of sectoral diversity in innovative activity and is aimed at analysing the impact of sectoral diversity on the dynamic relation between technology and the export performance of countries. The work comprises three sections. In Section 2, the theoretical issues underpinning the relation between technology and trade and

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sectoral diversity are analysed. The ensuing empirical work is in two parts. In the first, the importance of sectoral diversity is analysed through a descriptive analysis of the data (Section 3). Section 4 contains the econometric specifications and the results of the analysis of the link, in different sectors, between technology and export performance dynamics. Section 5 concludes.

## 2. The conceptual framework

### 2.1 *The sources of competitive advantage*

The unsatisfactory performance of the empirical tests of the multi-factor Heckscher, Ohlin, Samuelson explanations of trade patterns<sup>1</sup> (Krugman, 1995; Treffer, 1993; Bowen *et al.*, 1987) has shifted the attention of international trade theories towards the dynamic role of innovation and technical change. The main point of neo-technology theories in international trade, which draw on the technological gap and product cycle traditions begun by Posner (1961) and Vernon (1966), is that countries can be ranked by technological level (in terms of labour requirement in every industry), and goods can be ranked by technological intensity. Countries which are high up in the technological scale tend to specialise in technologically intensive goods. Moreover, process or product innovations occur, generating patterns of trade. Eventually, imitation narrows the technological gap and therefore the trade advantage of advanced countries is based on the temporary monopoly power generated by a continuous flow of new innovations (Krugman, 1979, 1994).<sup>2</sup>

A variety of models extends this analysis and links it to the endogenous growth framework, showing that resource allocation depends upon economic context (in particular, the endowment of skilled labour) and, especially, on the nature of knowledge spill-overs (Grossman and Helpmann, 1991; Grossman, 1991). Resources devoted to R&D affect crucially the patterns of trade, in a steady-state equilibrium, and, if a country has an abundance of skilled labour, it will specialise in R&D and the production of high-technology goods.

These models also provide an attempt to bring into the picture the possibility of knowledge capital accumulation through local and global exchange of non-rival and non-excludable intangible ideas. Modelling exercises show that, if technological spill-overs are global in scope (i.e., there is a world-wide common knowledge base, which is a function of the amount of differentiated product in the world economy), the relative abundance of human capital generates a comparative advantage in high-technology sectors because of higher R&D performance (Grossman and Helpmann, 1991, ch. 7). If spill-overs are local (i.e., knowledge capital accumulates in proportion to national research activity), a small technological lead might suffice to become a world leader in a specific industry, under the assumption that trade partners do not really differ in terms of relative skill endowments (Grossman and Helpmann, 1991, ch. 8).

These models, which have powerfully brought the relation between technology and trade to the top of the neo-classical agenda, have been questioned on the ground of that

<sup>1</sup> The Heckscher, Ohlin, Samuelson tradition, in its basic formulation, claims that a country relatively abundant in factor  $k$  will have a comparative advantage in the commodity which uses a relatively higher proportion of that factor and becomes specialised and exports this  $k$ -intensive good.

<sup>2</sup> Krugman (1995, p. 360) writes, "Today it is normal for trade theorists to think of world trade as largely driven by technology differences between countries; to think of technology as largely driven by cumulative processes of innovation and the diffusion of knowledge; to see a possible source of concern in the self reinforcing character of technological advantage; and to argue that dynamic effects on technology and growth represent both the main gains from trade and the main costs of protection".

they are too flexible and rely upon specific assumptions on the functional forms. At the same time, as recognised by Krugman (1995, pp. 359–60), it is difficult to give these model an operational content in terms of empirical work.<sup>1</sup>

In this paper, a different neo-Schumpeterian-evolutionary perspective is put forward. This approach shares with the neo-technology literature in international trade the idea that competitive advantages are built endogenously and their evolution depends importantly upon R&D and innovation activities. In the last 20 years, a considerable amount of rather sparse theoretical and empirical work has assessed the patterns of technological specialisation and competitive advantages at the empirical level, and investigated the microeconomic foundations of a theory of innovation. On the one hand, this has led to a more detailed account of the nature of technological knowledge bases, knowledge spillovers and, as a result, of the emergence of technological gaps in some industries. On the other hand, a set of stylised facts has been underlined. First, neo-Schumpeterian studies have emphasised that countries increasingly specialise technologically in different sectors (Patel and Pavitt, 1994; Archibugi and Pianta, 1992, 1994) and, at the same time, converge in terms of R&D intensity. Second, they have stressed that the number of competing countries at the technological frontier expands, and each nation has its own distinctive technological profile: no evidence of a hierarchical ladder emerges across industries in terms of country technological sophistication (Archibugi and Pianta, 1994; Archibugi and Michie, 1998; Vivarelli and Pianta, 2000).

Still, wide international differences in labour productivity occur and countries' relative advantages depend on the reproduction over time of differentiated technological knowledge and experience (Dosi *et al.*, 1990, ch. 3 and 5; Patel and Pavitt, 1994; Amendola *et al.*, 1998). Finally, evidence consistently shows that the dynamic of technological variables (world patent shares, relative R&D expenses, fixed investment) and the quality and novelty of products and productive processes affect importantly the dynamic of world market shares in advanced countries (Fagerberg, 1988; Dosi *et al.*, 1990; Greenhalg, 1990; Amendola *et al.*, 1993; Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995).

At the theoretical level, neo-Schumpeterian and institutionalist studies account for these stylised facts by starting from a detailed analysis of the processes of knowledge creation and diffusion at the microeconomic level. First, the literature has pointed to technology as a multi-dimensional concept (Nelson and Winter, 1982, Laudan, 1984, Dosi, 1988; Malerba, 1992), which includes a specific set of industrial methods and systems of production and knowledge which is not always freely available in blueprints, manuals and operating instructions, just as exogenous science is not. Since the technological knowledge base is built on previous experience, on formal and freely available knowledge and on learning processes about uncoded and tacit understanding and competence, the technological opportunity frontier is limited and guided by the specific procedures that agents build within a specific set of institutional interactions (Dosi, 1988).

This characterisation of technology leads to a conceptualisation of the innovation process which affects both the nature of international technological competition and trade between firms, regions and countries, and the sectoral patterns of innovative activity and industrial organisation. In particular:

- (1) Trade flows are based mainly on absolute advantages. The sectoral distribution of technological activities and exports does not depend upon relative adjustments between sectors within countries based on relative factor prices and quantities. Rather,

<sup>1</sup> See Gustavsson *et al.* (1999) for a recent attempt.

it depends upon specific and cumulative national trajectories which might lead to an absolute advantage in a specific sector in a specific country (Dosi *et al.*, 1990; Amendola *et al.*, 1993).

- (2) There cannot be a long-run equilibrium configuration of the sectoral distribution of activity and trade because the process of technological competition implies, at least in a first approximation, trajectories along fixed coefficient and irreversibilities. Therefore, it is the outcome in terms of sectoral world market share dynamics, together with the sectoral composition of demand,<sup>1</sup> which guides the pace of structural changes within countries (Dosi *et al.*, 1990; Amendola *et al.*, 1993).
- (3) Competition is a process of active rivalry and struggle for market shares between differentiated agents (Metcalfe, 1998, ch. 1). The point, then, is to investigate the relation between relative changes in national technological effort and outcomes in terms of competitiveness that can be expressed in terms of changes of world market shares within the same industry.

### 2.2 *The sources of sectoral specificity*

The microeconomic account of the innovative process outlined above implies also sectoral diversity in the relation between relative technological effort and the dynamics of market shares. Sectoral diversity emerges at least along three dimensions. First, the probability of achieving an innovative outcome, the conditional likelihood of continuing to innovate (cumulativeness) and the variety of possible solutions emerge within a specific set of technological characteristics<sup>2</sup> (Malerba and Orsenigo, 1997). Breschi *et al.* (2000) show thoroughly that intra-industry and external technological opportunity conditions importantly affect the sectoral patterns of innovative activity.

Second, economic agents are influenced in their innovative choices by the structure of incentives which, in turn, are affected by the appropriability conditions (Levin *et al.*, 1987; Dosi, 1988; Malerba and Orsenigo 1997; Breschi *et al.*, 2000). The choices of the appropriability means (patents, secrecy, continuous and cumulative R&D, learning curve effects, service efforts to protect their product and process innovations) are again, to a great extent, sector specific, because it is the technological content of the economic activity which determines the appropriate mean of reaping economic benefit from innovation (Levin *et al.*, 1987).

Finally, our characterisation of the innovative process suggests that sectors differ in the organisational rules and institutional arrangements according to which technical change processes take place<sup>3</sup> (Dosi, 1997; Malerba, 2000). Different knowledge bases require different sources of information and different procedures for solving problems. This means,

<sup>1</sup> Demand patterns are important for country sectoral specialisation for at least two reasons. First, as emphasised by Pasinetti (1981), income and substitution elasticities drive the process of structural change within and between countries. Second, sophisticated home markets on the demand side are known to be an important determinant for specialisation also in the supply-side sectors as emphasised by Linder (1961) and Lundvall (1992) and empirically tested by Fagerberg (1995). At the same time, in this paper, the focus is not on the relation between patterns of demand and export specialisation but, rather, on the impact of relative technological effort upon rates of growth of export shares.

<sup>2</sup> Technological life cycles, for example, can determine the level of technological opportunities and the reliance upon external scientific research (Utterback and Abernathy, 1975; Soete, 1981; Klepper, 1996).

<sup>3</sup> A noteworthy amount of recent literature has focused on the concept of system of innovation in order to analyse the mechanisms by which institutions and non-firm organisations support firm innovative activity (Nelson, 1993; Edquist, 1997). The innovation system concept has been used to study the degree to which a specific regional/national institutional environment is conducive to innovative activity. At the same time, the importance of sectoral diversity in defining the typology of the interfaces between firms and institutions has also been recognised (Nelson, 1993, ch. I; Metcalfe, 1995; Breschi and Malerba, 1997; Malerba, 2002).

for example, that sectors vary in firms' reliance upon formal scientific research performed in external agencies or universities or in the intensity and stability of firms' interactions with other firms in vertically linked sectors. If knowledge bases integrate different scientific and engineering disciplines, innovation is about assembled products and is the result of the interaction of designers, material and component producers (aircraft, computer mainframe and motor vehicles). Conversely, when knowledge bases refer to a specific scientific field, innovation relies less on suppliers of intermediate goods and more on direct scientific inputs (chemicals, pharmaceutical, synthetic fibres).

### 2.3 *The hypothesis to be tested*

Our discussion suggests three consequences with a strong evolutionary flavour. First, it can be claimed that countries differ in the rate and direction of technological change for each specific sector and that they show a considerable degree of continuity over time in the patterns of technological specialisation (the principle of heredity at country and firm levels).

Second, it implies that sectors differ in the relation between technology and market shares dynamics. The characteristics of the specific technological and learning regime affect patterns of innovation activity and, in turn, the industrial rules, which translate technological investments in market shares gains. Therefore, different sectors can be viewed as different populations of firms competing on the basis of specific organisational rules.

Finally, given the heterogeneity and the principle of heredity at a micro level, there must be a coordination mechanism that guides and constrains the relative weights of the population entities. A selection equation for each sector is then defined which connects the variety of behaviours to the different trajectories of change.<sup>1</sup> In sum, the relation between technology and trade and its sectoral specificity will be assessed on the basis of the following specification:

$$\dot{s}_{ij} = f_i(\dot{a}_{ij} - \dot{\bar{a}}_i) - g_i(\dot{c}_{ij} - \dot{\bar{c}}_i), \quad (1)$$

$\dot{s}_{ij}$  is the growth rate of country  $j$  export market share in sector  $i$ ,  $\dot{a}_{ij}$  and  $\dot{c}_{ij}$  are respectively the country  $j$  specific technological capabilities and unit costs rates of change ( $\dot{\bar{a}}$  and  $\dot{\bar{c}}$  are rates of change of the cross country average in sector  $i$ ).

In equation (1), it is assumed, first, that the dynamics of countries' world market share are importantly affected by a vector of country-specific cost and technological variables. This builds upon Soete (1981), Dosi *et al.* (1990) and Amendola *et al.* (1993), who show that the variance in the dynamics of export shares can be related to international differences in innovative activities.

Second, we take up the evolutionary argument that emphasises the role of interaction between entities to produce differential rates of growth of the population members. Accordingly, the understanding of export market shares dynamics of countries has to be grounded on the relative distribution of countries' behaviours, and the selection equation (1) is proposed in order to assess the way relative embodied and disembodied technological investments (which affect  $\dot{a}_{ij}$ ) and cost reductions affect market share dynamics.

Finally, a dynamic equation is adopted such that sectoral specificity is embedded in

<sup>1</sup> Static and dynamic selection mechanisms and replicator dynamic processes are used and discussed in Phelps and Winter (1970), Nelson and Winter (1982), Winter (1984), Silverberg *et al.* (1988); Amendola *et al.* (1993), Dosi *et al.* (1995), Metcalfe (1998), Malerba *et al.* (1999).

the functional form. This adds to the existing evidence on sectoral specificity in the determinants of competitiveness. In particular, Amable and Verspagen (1995) try to map the results of their regressions into Pavitt's taxonomy. They distinguish price and non-price factors in determining competitiveness and find mixed evidence. Expectations, based on this taxonomy, correspond to price factors coefficients values. Conversely, non-price factors coefficients, while showing important sectoral differences, cannot be interpreted through the same taxonomic lens. They conclude that: 'there is still a need for a theory that can be applied in a broader field than just the one inspired by "institutional economics"' (Amable and Verspagen, 1995, p. 204). Magnier and Toujas-Bernate (1994) also find substantial sectoral diversity. In particular, although competitiveness in Aerospace and Office Machinery shows high sensitivity to R&D expenses, their estimations do not display a clear correlation between the technological contents of the sectors and their sensitivity to R&D expenses.

### 3. R&D intensity and competitive advantages. preliminary evidence

Sections 3 and 4 merge two standard databases (STAN, Structural Analysis Industrial Database, and ANBERD, Analytical Business Enterprise R&D, OECD, 1996 A,B, 1997 A,B) to explore the extent to which the hypothesis of sectoral diversity is accounted for in standard economic indicators and in the relation between technology and export performance. The analysis is based on indicators of business enterprise R&D expenses (BERD), gross fixed capital formation (GFCF: machinery, equipment, buildings, land), labour costs and export. Tables A1 and A2 in the Appendix provide a description of the data set.<sup>1</sup>

#### 3.1 R&D intensity

There is no unified criterion to make taxonomies out of the idea of sectoral technological intensity. It follows from our previous discussion, however, that, in some sectors, commercial and productive activity is linked more substantially to efforts in research and development of new processes and products and to a more complex technological knowledge base. OECD (1986, p. 59) lists a set of characteristics which are normally related to high-technology sectors: the need for strong R&D, the strategic importance for governments, very rapid product and process obsolescence, high risk and large capital investments and, finally, a high degree of international cooperation and competition in R&D production and world-wide marketing.

Following OECD (1986), the first of these criteria is used, and sectors are ordered according to R&D intensity (the ratio of R&D expenditure to production). The period considered runs from 1980 to 1991 and data are grouped in three sub-periods of four

<sup>1</sup> The choice of the sectors and countries responds to relevance and data availability criteria and guarantees a sufficient degree of diversity in terms of technological content and country characteristics. It is acknowledged that sectoral disaggregation might be too broad. At the same time, the literature on National and Sectoral Innovation Systems (see footnote 3 on p. 526) has emphasised that part of the variance in terms of innovative and export performance at firm level can be explained with national/regional specific variables in specific industries. It has underlined that there are important characteristics of the institutional environment and of the organisations of industries (e.g., reliance upon formal scientific research performed in external agencies or universities or on the intensity and stability of firms' interactions with other firms in vertically linked sectors) that can underpin the analysis at this level of aggregation. Moreover, my paper makes a step forward with respect to Dosi *et al.* (1990) and Amendola *et al.* (1993), who provide evidence at a national level.

**Table 1.** Analysis of variance between and within sectors. Dependent variable: R&D intensity (sub-period: 1984–87, 12 sectors, 10 countries)

Source of variation.	df	Sum of squares.	Mean square.	F value.	Pr>F	R square.
Model (between sectors)	11	2,378.27	216.2	22.19	0.0001	0.69
Error (within sectors)	108	1,052.40	9.74			
Total	119	3,430.68				

years each (1980–83, 1984–87 and 1988–91). For each sub-period, the average value is calculated. Sectors are divided into high-, medium- and low-technology groups according to the criterion defined by OECD (1986). If the R&D/output ratio is greater than 4%, sectors are high technology (Aircraft, Computer and Office Machinery, Pharmaceuticals, Electronics). If the ratio is in the 1–4% interval, sectors are medium technology (Chemicals, Electrical and Non-electrical Machinery, Motor Vehicles). Otherwise, they are low technology (Textile, Food, Paper and Wood). For each sector, R&D intensity values are quite stable across country and through time, and the following evidence accounts for sectoral specificity:<sup>1</sup>

- (1) These categories are stable in the chosen sub-periods. Considering the R&D intensity values for each country in two different sub-periods, correlation coefficients are significantly different from zero (Table 2, point 1).<sup>2</sup>
- (2) The analysis of variance shows that the variance between sectors accounts for more than two-thirds of the total variance. The hypothesis that the mean is constant across sectors is rejected (Table 1).
- (3) Sectoral R&D intensity is significantly correlated cross-country (Table 2).<sup>3</sup>

Looking at R&D intensity, then, it appears that sectoral differences are stronger than differences between countries. The characteristics of sectoral R&D intensities are persistent across countries and through time. The discussion in Section 2 can account for these differences. In particular, different technological paradigms imply a sectoral variance of the modes of innovative search, which depends on the characteristics of the technological opportunities and on the variety of potential innovations and ease of achieving them. The development of knowledge bases in aircraft technologies, computers, electronics and pharmaceuticals relies more importantly on research, and this affects the organisational rules of the innovative activity. In microelectronics, for example, R&D levels and cumulative R&D are also an important means of appropriability. Moreover, it may be noted

<sup>1</sup> In this descriptive exercise, only ten countries are used out of 14 (see Table A2). Australia and the Netherlands are not considered. R&D intensity in Electronics in Netherlands ranges from 38% to 66%, and R&D intensity in the Electrical Machinery in Australia is between 73% and 109%. These cases represent very interesting outliers, which need further enquiry on the specific characteristics of these countries, which is beyond the scope of this paper. Note that the values of R&D relative effort (discussed below) for Electronics in the Netherlands and Electrical Machinery in Australia are in line with the country values in the other sectors. Moreover, this analysis does not include Denmark, because R&D data are missing in the Motor Vehicles sector, and Norway, because R&D data are missing in the Aircraft sector. Italy is excluded from the third sub-period for missing data.

<sup>2</sup> Here and throughout Section 3 the null hypothesis is rejected at significance level of 15%.

<sup>3</sup> Results (2) and (3) hold in all the sub-periods considered. Tables for sub-periods one and three are not reported and are available from the author.

that, to a great extent, in three high-technology sectors (Aircraft, Electronics and Com-

**Table 2.** Correlation tables. Variable R&D Intensity ( $r = \text{Pearson product-moment correlation}$ ,  $P$  values are obtained from  $t = r/[(1 - r^2)/(n-2)]^{1/2}$ .  $t$  comes from a  $t$  distribution with  $n-2$  degrees of freedom,  $H_0: r = 0, H_1: r > 0$ )

(1) Correlation between the first and the third sub-periods ( $N = 12$ ; for Italy $N = 10$ , $P$ values in parenthesis)											
	CAN	FIN	FRA	GER	ITA	JAP	SPA	SWE	UK	US	
R	0.99	0.95	0.99	0.99	0.84	0.96	0.97	0.95	0.76	0.94	
P values	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.003)	(0.0001)	(0.0001)	(0.0001)	(0.004)	(0.0001)	
(2) Cross-sector correlation matrix: first sub-period ( $N = 12$ . $P$ values in parenthesis)											
	CAN	FIN	FRA	GER	ITA	JAP	SPA	SWE	UK	US	
FIN	0.60 (0.04)										
FRA	0.88 (0.002)	0.58 (0.05)									
GER	0.74 (0.006)	0.36 (0.25)	0.94 (0.0001)								
ITA	0.85 (0.0005)	0.57 (0.05)	0.97 (0.0001)	0.95 (0.0001)							
JAP	0.56 (0.06)	0.76 (0.004)	0.81 (0.001)	0.77 (0.004)	0.82 (0.001)						
SPA	0.62 (0.03)	0.11 (0.74)	0.78 (0.003)	0.94 (0.0001)	0.86 (0.0004)	0.56 (0.06)					
SWE	0.55 (0.06)	0.79 (0.002)	0.80 (0.002)	0.70 (0.01)	0.78 (0.0028)	0.92 (0.0001)	0.47 (0.12)				
UK	0.77 (0.003)	0.80 (0.002)	0.92 (0.0001)	0.83 (0.0009)	0.92 (0.0001)	0.94 (0.0001)	0.64 (0.03)	0.93 (0.0001)			
US	0.89 (0.0001)	0.61 (0.03)	0.93 (0.0001)	0.88 (0.0002)	0.98 (0.0001)	0.77 (0.003)	0.80 (0.001)	0.71 (0.01)	0.90 (0.0001)		

puters and Office Machinery) innovating firms are larger (and thus a higher likelihood of engaging in R&D) and innovative activities tend to be concentrated (Malerba and Orsenigo, 1995).

Still this does not rule out country differences, since the 'within sectors' variance is one-third of the total R&D intensity variance. In particular, a higher value of country average R&D intensity (weighted by sectoral shares on countries' total output) is found in the US, the UK, Sweden, Germany and France.<sup>1</sup> In Japan, Italy, Finland and Sweden, it increases significantly in all three sub-periods. Moreover, in all countries, average R&D intensity increases between the first and the third sub-period (except for the UK, which passes from third position in the first sub-period to sixth position in the last sub-period). In all countries (excluding Italy), this change is composed of two parts. First, there is an increase of R&D intensity in almost all sectors. Second, in all countries, sectoral shares in a country's total output tend to shift in the direction of high-technology sectors.

Following our argument in Section 2, country differences should also be captured using an index of relative R&D effort in each industry. Accordingly, the amount of R&D expenditure in sector  $i$  and country  $j$  divided by the aggregate R&D expenditure of all countries in the same sector (not controlled for the size effect) is calculated.<sup>2</sup> Country diversity depends, first, on country size and on the amount of firms active in R&D and on their average size. Second, it can indicate superior quality and higher variety of products. Third, as stressed by the literature on National Systems of Innovation, country-specific institutional factors can affect firms' propensity to innovate, and their choices of location of research and innovative activities.

The data show that two-third of total R&D is performed in the US and Japan. This is true for all sectors, apart from Pharmaceuticals, Chemicals and Non Electrical Machinery, where European countries, in particular Germany, account for an important share of total R&D. The distance in terms of absolute R&D between the US and other countries is greater in the high-technology, motor vehicles and paper sectors. Relative R&D for Japan shows a 30% increase between the first and the third sub-period. This change is higher than the 40% in Computers and Office Machinery, Electrical Machinery, Electronics, Paper and Aircraft, which is still very small relative to Japanese R&D expenditures.

### 3.2 *Absolute advantages and revealed comparative advantages*

The analysis of the nature of sectoral diversity can be also considered in terms of export indexes. In particular, two indexes are calculated: the revealed absolute advantage (consistently with the previous section, they are the ratio of export of country  $j$  in sector  $i$  to sectoral aggregate of all countries) and revealed comparative advantage (RCA). Revealed absolute advantages are used to study the world market share of country  $j$  in sector  $i$ . Conversely, RCAs are more appropriate for explaining trade specialisation of countries and changes in the sectoral allocation of exports due to changes in factor prices and sectoral levels of profits. It is worthwhile noting that  $RCA_{ij}$  can increase either because of an effective improvement of competitiveness in sector  $i$ , or because of deterioration in the export performance of the other sectors in the economy of country  $j$ .

<sup>1</sup> The tables on country average R&D intensity, countries' relative R&D effort (see below) and trade absolute and revealed comparative advantages (see below) are not reported and are available from the author.

<sup>2</sup> R&D intensity expresses the relative R&D effort of firms independently of the country dimension and of the total amount of firms. At the same time, absolute levels of R&D expenditures are considered a better indicator when there is an absolute R&D threshold at a firm level in order to produce a new variety of a product. In the following sections, we test the impact on export market shares dynamics of the rates of variation of both the indicators.

Following our discussion in Section 2, an index of absolute advantage is used in order to relate country  $j$ 's export performance to the technological effort (relative to the other countries) of country  $j$  within the same sector. The absolute advantage index is affected by countries' size. Three points can be raised in relation to this. First, theories of technological gap and of national innovation systems claim that firms' efficiency distribution is not the same within each country (Dosi *et al.*, 1990; Nelson, 1993). In this case, world market shares can be an appropriate index of international sectoral competitiveness, because they would reflect this difference across countries in firms' average efficiency levels. Second, the size effect has a different weight depending on the different sector. Moreover, there are important differences in world market shares among countries of similar size. Finally, the normalisation of exports with a size indicator returns an index of countries' trade openness. European countries would have a greater value than, for example, the US or Japan.

The stylised facts highlighted in this section can be summarised as follows:

- (1) More than half of world exports come from the US, Germany and Japan. Taking into account the size effect, these countries also have the highest values of relative R&D effort in all sectors.
- (2) Revealed absolute advantages are fairly stable in the three sub-periods. This confirms the specific and cumulative character of sectoral success factors in each country. Within this framework, in HT sectors, the market shares gain of Germany and the decline of the US are noteworthy.
- (3) Sectoral diversity emerges in the different values of cross-country market shares variance. The dispersion is, on average, lower (but increasing in the three sub-periods) in the LT sectors. In HT and MT sectors, products are often 'complex systems'. Technical advancements in these sectors stem from the interaction of component and material producers and designers. The systemic features and complexity of the knowledge basis suggest that in these sectors the emergence of cumulative learning processes and dynamic increasing returns, which increase asymmetry in the competitive performance of countries, is more likely.
- (4) RCAs show different patterns of export specialisation in different countries, which are stable in the three sub-periods<sup>1</sup> (the values of the correlation coefficients, not reported, are not in general significantly different from zero). Export specialisation is similar in the UK and US; in Finland, Sweden and Canada, and, finally, in France, Spain and Netherlands.

#### **4. The relation between export market shares, investment, R&D expenditure and labour costs and patterns of sectoral diversity**

##### *4.1 A cross-country analysis*

In this section, a first step is made to explore the relation between market shares, investment, R&D expenditure and labour costs and to find out whether any significant pattern of sectoral diversity emerges. The following variables are considered:

<sup>1</sup>This is a common theme in international economics and is traditionally accounted for by the stability of the relative intensity of production factors, by the emergence of firm-level economies of scale and increasing returns, and by the presence of external economies. At the same time, it may be noted that this circumstance does not contradict the idea that technological knowledge bases are not perfectly transferable. In particular, in the high- and medium-technology sectors, a different path of relative specialisation may reflect a differentiated distribution of competence and the emergence of cumulative processes of learning (see Grossman and Helpman, 1991; Krugman, 1995; Dalum *et al.*, 1999).

$$REXP_{ij} = EXP_{ij} / \sum_j EXP_{ij} \quad (i = 1, \dots, N; j = 1, \dots, M)$$

$$RRD_{ij} = RD_{ij} / \sum_j RD_{ij} \quad (i = 1, \dots, N; j = 1, \dots, M)$$

$$RCF_{ij} = CF_{ij} / \sum_j CF_{ij} \quad (i = 1, \dots, N; j = 1, \dots, M)$$

$$RLC_{ij} = LC_{ij} / ALC_i \quad (i = 1, \dots, N; j = 1, \dots, M)$$

$N$  is the number of sectors,  $M$  the number of countries (Table A2),  $EXP_{ij}$  is the total country  $j$  export in sector  $i$  (US\$-PPP),  $RD_{ij}$  is the business enterprise R&D expenditure in sector  $i$  and country  $j$  (US\$-PPP);  $CF_{ij}$  is the gross fixed capital formation in sector  $i$  and country  $j$  (US\$-PPP),  $LC_{ij}$  is the labour costs per employee in sector  $i$  and country  $j$  (US\$-PPP);  $ALC_i$  is the weighted average of  $LC_{ij}$  in sector  $i$ , and R&D and CF are chosen in order to reflect two different aspects of the technological content of the economic activity within industries (Pianta, 1995; Magnier and Toujas-Bernate, 1994). In particular, R&D expenses can be considered a proxy for technical change based on creation of new knowledge and therefore with a disembodied nature (as, for example, the one provided by industrial research institutes and borderline institutions). At the same time,  $CF$  can index the technological improvements embedded in investment flows and in the acquired capital goods obtained through diffusion flows.<sup>1</sup>  $LC$  is a control variable and can also be expected to approximate the value of the quality of human capital (see the following section for a discussion).

As indicated above, world market shares in each country are calculated in terms of export, R&D expenditure and gross fixed capital formation (all variables are expressed in US\$-PPP, see OECD, 1997). Moreover, in each country the level of labour compensation per employee in sector  $i$  has been assessed relative to the weighted average across countries in the same sector  $i$ . Consistently with the previous section, average values in the three sub-periods (1980–83, 1984–87, 1988–90) are calculated. There are 149 observations (for each sub-period) according to the number of countries used in each sector, as shown in Table A2. The three sectoral samples are made up of high- (47 obs.), medium- (50 obs.) and low-technology (52 obs.) sectors.

To perform the regression analysis, the percentage change in the variables between the sub-periods (between the third and the second and between the second and the first) is calculated. First, expressing variables in terms of growth rates grasps better the dynamic relation between countries technological relative efforts and competitiveness (see

<sup>1</sup>The link between R&D and technological output is complex and is only partly grasped in the following econometric equations (2), (3) and (4). First, R&D expenditure does not always translate into tradable processes and products; second, as stressed by Fagerberg (1988), capacity constraints at firm level and firms' ability actually to exploit R&D output should be taken into account, in particular for the European case. Moreover, in this paper, technological spill-overs and externalities are not explicitly considered (Pavitt, 1984; Verspagen and De Loo, 1998). Since R&D expenditures are reported on a territorial basis, the three variables not only do not take into account technological transfers across macro-sectors, but also underestimate transfers which take place within firms. This problem is partially overcome, considering that cross-country variance of these effects is limited in our sample because all countries are advanced. Moreover, as noted by Amendola *et al.* (1993), acquisition and localisation processes of multinational firms respond to the technological sophistication reflected in the values of the variable chosen in this paper.

<sup>2</sup>As may be noted from Table 3, the number of observations amounts to 293 and not 298 as it should be, because of the pooling the two sub-samples which incorporate variables' percentage changes between the second and the first sub-period and between the third and the second sub-period (149 obs. each). Five observations are left out. These refer, for the first sub-sample, to the wood industry in Italy, the Netherlands and Spain, and to textiles in Italy, and for the second sub-sample, to wood in Spain. In these five cases, the values of R&D relative effort growth rates turn out to be much higher than the average. This is because the initial value is very small. Moreover, the R&D intensity values in the wood industry in Italy and Spain and in Textiles in Italy (in the first period) are by far the smallest.

Table 3. POLS estimates of equation (2)

Indep. var.	High tech.		Medium tech.		Low tech.	
	(i)	(ii)	(i)	(ii)	(i)	(ii)
$\Delta RRD$	0.12*** (2.4)		0.05 (0.86)		0.05 (0.88)	
$\Delta RCF$	0.01 (0.25)		0.17*** (2.16)	0.18*** (2.45)	0.07 (0.91)	
$\Delta RLC$	0.0003 (0.01)		0.05 (0.13)		-0.28 (-0.78)	-0.5* (-1.46)
$\Delta RRD \times \Delta RCF$		0.13** (1.7)				0.38*** (2.43)
$\Delta RRD \times \Delta RRD$		0.08*** (2.46)				
$\Delta RCF \times \Delta RCF$		-0.09*** (-2.37)				
$\Delta RCF \times \Delta RLC$		1.57** (1.91)				
$\frac{\partial \hat{E}[\Delta REXP]}{\partial \Delta RRD}$	0.12	0.08				0.03
$\frac{\partial \hat{E}[\Delta REXP]}{\partial \Delta RCF}$		0.07	0.17	0.18		0.04
$\frac{\partial \hat{E}[\Delta REXP]}{\partial \Delta RCL}$		0.20				-0.5
$N$	293	293				
$F$	3.68***	6.06***				
$R_{Adj}$	0.13	0.16				

Notes:  $t$  test in parenthesis. Levels of significance: \* 85%, \*\* 90%, \*\*\* 95%.

Fixed effects included when significantly different from zero.

No heteroscedasticity detected in the POLS estimates (White tests).

No multicollinearity (Variance inflation numbers and condition number).

The calculation of marginal effects follows Greene (1997; pp.391–2).

Variables:  $\Delta REXP$  (dep. var.) is the percentage growth of world export market share in country  $j$  and sector  $i$ .

$\Delta RRD$  is the percentage growth of world share of R&D per employee in country  $j$  and sector  $i$ .

$\Delta RCF$  is the percentage growth of world share of CF per employee in country  $j$  and sector  $i$ .

$\Delta RCL$  is the percentage growth of the ratio of labour compensation per employee in sector  $i$ , country  $j$  relative to the weighted country average in sector  $i$ .

equation 1). Second, it allows us to get rid of the size effect that would also generate multicollinearity between the variables. Moreover, slope dummy variables for high-, medium- and low-R&D intensity industries are included in order to test for sectoral diversity (subscript  $h$  refers to the three technological categories (HT, MT, LT) in which sectors are grouped). Accordingly the following specification is tested:<sup>2</sup>

$$\Delta REXP_{hj} = \mu_h + \mu_j + \beta_h \Delta RRD_{hj} + \gamma_h \Delta RCF_{hj} + \delta_h \Delta RLC_{hj} + \varepsilon_{hj} \quad (2)$$

Columns (i) in Table 3 show the estimates of specification (2) and the total marginal effects. In addition, the linear functional form is controlled by a formulation which includes interaction and squared terms. Significant estimates and total marginal effects are reported in columns (ii).

The estimated coefficients do not reject the hypothesis that differences in the technological content of sectors affect the relation between technological variables and export market shares. In particular, in the high-technology sample, R&D relative effort coefficient is significantly different from zero, while the capital formation parameter is not statistically significant. The opposite occurs in the medium-technology case, where estimated  $\gamma$  is significantly different from zero, while estimated  $\beta$  is not.

It is worth emphasising that, looking at the result in column (i), the labour cost coefficient is not statistically significant for all sectors. In low-technology sectors, positive changes in the relative labour cost coefficients seem to play a negative role in the determination of world market shares dynamics. However, estimated  $\delta$  cannot be considered statistically different from zero.

The linear functional form is controlled by a formulation which includes interaction and squared terms (column ii). Consider first the complementarity effect between embodied and disembodied technological improvements. The estimated relation between the relative R&D rate of investment and export market share dynamics might not be independent from the relative rate of growth of the investment in fixed capital. In particular, it is plausible that market share dynamics are affected by a specific combination of growth of R&D and fixed capital. Therefore an interaction term ( $\Delta RCF \times \Delta RRD$ ) is added which tests whether the marginal effect of higher R&D investment on export performance is increased when the rate of growth of fixed capital formation is higher.

The results show first that, both in the high-technology and low-technology industries, the interaction term estimates do not reject the hypothesis that export performance is affected by a specific combination of embodied and disembodied technological advancements. In particular, since for these two sectors  $\Delta RCF \times \Delta RRD$  is significantly positive, we can claim that the positive relation between the  $\Delta RRD$  and  $\Delta REXP$  is higher in the presence of higher relative growth of investment in fixed capital. At the same time, it is equally correct to claim that the positive relation between  $\Delta RCF$  and  $\Delta REXP$  turns out to be stronger in the presence of higher  $\Delta RRD$ .

Second, only in the high-technology industries is the interaction effect between growth in relative capital formation and changes in the relative labour cost significantly positive. This means that a higher value of  $\Delta RLC$  improves the effect of a higher  $\Delta RCF$  on world market shares. This circumstance can be interpreted in two ways. On the one hand, capital formation can be more successful if the quality of human capital improves. This means that, in the high-technology sectors, countries which combine relatively higher investment in machinery and equipment and a well-paid labour force improve their trade performance. The evidence that this interaction is significant only in high-technology sectors also supports this point of view. On the other hand, an increased level of relative labour costs could foster factor substitution and then capital formation which, in turn, improves export market shares.

Finally, non-linearity in the relation between relative technological effort and export market share dynamics has also been tested by including the squared terms for  $\Delta RCF$  and  $\Delta RRD$ . Estimates show that, in the high-technology sectors alone, the squared term of  $\Delta RRD$  is significantly positive, while the squared term for  $\Delta RCF$  is significantly negative. This means that, in the case of R&D, the marginal effect of  $\Delta RRD$  on  $\Delta REXP$  turns out to increase with the value of  $\Delta RRD$  itself. In the case of  $\Delta RCF$ , the return in terms of export market shares decreases with  $\Delta RCF$ . It turns out, therefore, that the probability of observing that country  $i$  is increasingly competitive in a high-technology sector increases more than proportionally in relation to the changes in the rate of relative variation in R&D

investment. At the same time, these results suggest that export performance is most likely to be associated with higher investment in gross fixed capital, but only up to a certain threshold. *Ceteris paribus*, there is evidence that increased  $\Delta RCF$  might show decreasing returns in terms of competitive gains. This reinforces the idea that improvements in export shares are the result of the combination of the adoption of new equipment which embodies technological advances and the development of a qualified labour force.

Summing up, this exercise has shown that, if a country increases its technological effort in a specific industry relatively to its trade partners, it can achieve competitive gains in terms of export world market shares. In the high-technology sector, relative effort in terms of disembodied technical change is particularly important. Evidence suggests increasing returns in the relationship between relative R&D investments and market shares gains. Moreover, gains in terms of market shares for a country are higher if R&D is also complemented, in the same industry, by higher investments in fixed capital relative to the other countries. In the high-technology sectors, a positive relationship also emerges between export gains and relative labour cost which is stronger in the presence of relatively higher technological improvements embodied in capital goods.

The relation between technology and exports shows different patterns in the medium- and low-technology sectors. In the medium-technology sectors, it is worthwhile noting the relevance of investment in fixed capital formation, while in the low-technology sectors, labour cost dynamics seems to affect the export performances of countries negatively, and relative technology effort is related to improvements in world market shares only through a combination of embodied and disembodied technological advances. In general, from specification (2), there is no evidence of a statistically significant relationships between changes in relative labour costs and export market share dynamics for the medium- and high-technology sectors.

#### 4.2 The dynamic specification

In this section, the relation between relative technological effort of countries and their export performance is studied in a dynamic framework. It is appropriate to emphasise that technological innovation processes are inherently dynamic and that in many empirical studies this feature has been neglected.<sup>1</sup> Here a panel-dynamic (DL) specification is used for each sector in order to extend equation (2) and to assess sectoral diversity from two points of view: (1) diverse coefficients' significance and magnitude in different sectors, (2) different structures of time lags.

The 'engines' which affect market share dynamics are: R&D per employee, Gross Fixed Capital Formation per employee and human capital (variables are normalised for the size effect). The dynamic relation between these variables and world export market shares is studied using the following equation:

$$X_{i,j,t} = \alpha_i + \mu_j + \tau_t + \sum_{l=0}^m \gamma_l RDL_{i,j,t-l} + \sum_{l=0}^n \delta_l CFL_{i,j,t-l} + \sum_{l=0}^g \varphi_l RLC_{i,j,t-l} + \varepsilon_{i,j,t} \quad (3)$$

$\alpha_i$ ,  $\mu_j$  and  $\tau_t$  correspond to sector  $i$ , country  $j$ , time  $t$  fixed effects;  $X_{i,j,t}$  is the rate of growth of the ratio of export in sector  $i$ , country  $j$  at time  $t$  to the world aggregate in sector  $i$  at time  $t$ ;  $RDL_{i,j,t}$  is the rate of growth of the ratio of R&D per employee in sector  $i$ , country  $j$  at

<sup>1</sup> Static relationships are estimated in Soete (1981), Dosi *et al.* (1990) and Fagerberg (1988). Dynamic specifications are tested in Amendola *et al.* (1993), Magnier and Toujas-Bernate (1994) and Amable and Verspagen (1995).

Table 4. POLS estimates of equation (3)

	Lags	All sectors <sup>b,c</sup>	HT <sup>b,c</sup>	MT <sup>c</sup>
RDL	0			
	1			
	2			
	3	0.03***	0.32***	0.06**
CFL	0	0.05***	0.07**	0.04**
	1			
	2			
	3	0.03**		
RLC	0			
	1			
	2	0.22**	0.42*	
	3			
	No. obs.	1,550	444	462
	F	6.27***	10.42***	4.97***
	adj R <sup>2</sup>	0.02	0.08	0.04
Tests		<sup>a</sup> F <sub>66,1477</sub> =5.06***	F <sub>12,427</sub> =5.36***	F <sub>6,453</sub> =1.11
		<sup>d</sup> X(13)=888.34***	X(12)=335.37***	X(12)=138.87***
		<sup>e</sup> X(11)=1615.90***	X(3)=159.92***	X(3)=42.97***

Notes: <sup>a</sup> Test of sectoral homogeneity of slope.

<sup>b</sup> autoregressive component is included when significantly different from zero.

<sup>c</sup> Country and sector fixed effects have been tested. Hypothesis of homogeneity of the intercept rejected.

<sup>d-e</sup> Heteroscedasticity: Breush-Pagan/Godfrey Test: countries (d) and sectors (e).

Significance levels: \*90%, \*\*95%, \*\*\*99%.

Variables: X (dep. var.): rate of growth of the ratio of export in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

RDL: rate of growth of the ratio of R&D per employee in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

CFL: the rate of growth of the ratio of GFCF per employee in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

RLC: the rate of growth of the ratio of labour compensation per employee in sector *i*, country *j* at time *t* to the weighted country average in sector *i* at time *t*.

time *t* to the world aggregate in sector *i* at time *t*;  $CFL_{i,j,t}$  is the rate of growth of the ratio of GFCF per employee in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*;  $RLC_{i,j,t}$  is the rate of growth of the ratio of labour compensation per employee in sector *i*, country *j* at time *t* to the weighted country average in sector *i* at time *t*.

The description of the number of sectors (12), countries (14) and years selected is provided in Table A2 in the Appendix. As stressed in the previous section, R&D and GFCF are proxies for the technological vitality of country *j* in sector *i*. The former reflects the disembodied nature of technological advancements, the latter approximates the technological improvements which are incorporated in new machinery and equipment. In addition, a relative labour cost index is calculated. Again, there are no *a priori* expectations about the sign of coefficient  $\varphi$  because, on the one hand, RLC may reflect wage changes in order to attract high-quality labour, and on the other hand, it represents an increased cost for the firms. Nevertheless evidence in the previous section supports the idea that in the high-technology sectors the more appropriate interpretation is the former. Since in this section the focus is mainly on high- and medium-technology sectors, RLC will be considered a proxy of the relative quality of human capital.

#### 4.3 Estimation results

First, consider the pooling of the 12 sectors. Pooled least squares estimates, shown in Table 4, do not reject the hypothesis of an important role played by the technological variables. *RDL*, *CFL* and *RLC* estimated parameters are significantly different from zero with a delay of three lags for *RDL*, zero and three lags for *CFL* and two years for *RLC*. POLS estimates do not pass the diagnostic check. First, the restriction of homogeneity of slopes is rejected, second, the Breush-Pagan/Godfrey Test (Greene, 1997, p. 552) reveals the presence of heteroscedasticity.

The following step is then to divide the sample into three sub-samples made up of high-, medium- and low-technology sectors. In Table 4, the results are reported for the first two categories. For the low-technology sectors the estimates do not give values which are significantly different from zero. This is not surprising since the adopted specification does not include important non-technological variables (marketing expenditure, specific price factors) which are probably crucial in traditional sectors. Moreover, in these sectors, innovation activity is less dependent on relative R&D expenditures. With respect to LT sectors, the result found in the previous section (Table 3) is lost in equation (3). This is probably due to the shorter-run character of this latter formulation and on the possible inertia in the effects that parameters  $\varphi$  attempt to embody.

However, some important sectoral specificities emerge in Table 4. The *RDL* estimated coefficient is greater in the case of high-technology sectors. It is suggested also that *RDL* acts with a greater delay than *CFL*. The *RLC* estimated coefficient is significantly different from zero only in the high-technology sectors at time lag 2. The positive sign suggests that human capital plays a role in supporting competitiveness gains in these sectors. These estimates, even if they provide some preliminary evidence on sectoral diversity, incur the following problems: first, heteroscedasticity is detected by the Breush-Pagan/Godfrey Test; second, the adjusted *R*-squared test shows that a great portion of variance remains unexplained; and, finally, the restriction of sectoral homogeneity of the slopes is rejected in two cases out of three.

Both the theoretical discussion in Section 2 and the evidence in Table 4 suggest continuing the analysis estimating equation (3) separately for each single sector. For each sectoral sample, heteroscedasticity has been detected. As a result, two-stage FGLS have been used on the following specification:

$$X_{j,t} = \mu_j + \tau_t + \sum_{l=0}^m \gamma_l RDL_{j,t-l} + \sum_{l=0}^n \delta_l CFL_{j,t-l} + \sum_{l=0}^g \varphi_l RLC_{j,t-l} + \varepsilon_{j,t} \quad (4)$$

( $j = 1, \dots, M$ ;  $t = 1, \dots, T$ );  $\mu_j$  and  $\tau_t$  are country  $j$  and time  $t$  fixed effects.

The estimates are shown in Table 5. For each sector, a restricted model with homogeneous intercepts has been tested against three models without restrictions on the intercepts (time and country fixed effects, country fixed effects and time fixed effects). This restriction has always been accepted except for the case of Telecommunications Equipment where time-fixed effects have been included. In all the regressions, an autocorrelation error diagnostic is implemented via the Box-Pierce and the Ljung-Box Tests (Greene, 1997, p. 595) for 1–4-year lags. The panel structure of the observations has been taken into account in the construction of these tests.

In Table 5, sectoral diversity emerges from a double perspective: in the statistical significance of the coefficients and in the time lag structure. Consider first the relationship between the relative effort in R&D and the dynamics of export shares. It is significantly

Table 5. FGLS estimates of equation (4)

R&D Intensity Lags	Computers							
	Aircraft	Office Machinery	Pharm.	Telecom Equip.	Electrical Machinery	Motor Vehicles	Chemicals	Non-electrical Machinery
<i>RDL</i>	15.7 <sup>a</sup>	11.7	10.9 <sup>a</sup>	7.9 <sup>b</sup>	3.4	3.37	3.37 <sup>a</sup>	2.0 <sup>a</sup>
<i>CFL</i>	0.72***		0.18**	0.17**	0.12***	0.10*		0.06*
<i>RLC</i>			0.09**		-0.07*	1.01*	-0.10*** 0.08*** -0.09***	0.18***
		1.41**				0.44*		0.36**
No. obs.	90	117	120	117	117	108	120	104
<i>F</i>	10.41***	3.22**	6.17***	2.74***	5.34***	3.87***	6.27***	7.17***
adj. <i>R</i> <sup>2</sup>	0.24	0.03	0.08	0.13	0.07	0.14	0.15	0.19
Test L-B <i>X</i> <sub>(3)</sub> (4 lag)	6.54	1.31	2.52	4.19	3.46	1.39	3.80	0.55

Notes: Autocorrelation diagnostic check: Breush-Pagan and Ljung-Box test for 1 to 4 lags. Only the Ljung-Box test for the fourth lag is reported. The value *c* such that  $\text{Prob}[X_{3,2 \leq c}] = 0.95$  is 7.82.

Multicollinearity diagnostic check: Condition number and variance inflation number. Not detected.

<sup>a</sup> Autoregressive component is included when significantly different from zero.

<sup>b</sup> The presence of fixed time effect is not rejected by the appropriate *F*-test.

Significance levels: \*90%, \*\*95%, \*\*\*99%.

Variables: *X* (dep. var.): rate of growth of the ratio of export in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

*RDL*: rate of growth of the ratio of R&D per employee in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

*CFL*: the rate of growth of the ratio of GFCF per employee in sector *i*, country *j* at time *t* to the world aggregate in sector *i* at time *t*.

*RLC*: the rate of growth of the ratio of labour compensation per employee in sector *i*, country *j* at time *t* to the weighted country average in sector *i* at time *t*.

different from zero in six sectors out of eight. This result confirms the role of relative R&D expenditure in affecting the export performance of countries. Moreover, it reinforces the empirical evidence already available, which often is not sectorally disaggregated (Soete, 1981; Fagerberg, 1988; Dosi *et al.*, 1990; Amendola *et al.*, 1993; Amable and Verspagen, 1995). Second, it is interesting to note the sectoral differences in the time lags necessary for R&D expenditure to affect export market shares. In Aircraft, Telecom Equipment and Motor Vehicle, the time lag is three years, in two Pharmaceuticals and Non-electrical Machinery it is two years and in Electrical Machinery it is one year.

In addition, an important regularity emerges. The values of parameters  $\gamma$ , which are significantly different from zero, are correlated with the sectoral R&D intensity. This result suggests that R&D intensity is an important cornerstone not only for understanding the technological content of the sectoral activity but also for evaluating the dynamic relation between relative R&D effort and market share dynamics.

It is surprising that coefficients  $\gamma$  are not statistically significant in the case of Computers and Office Machinery and Chemicals. The first is a high-technology sector. This non-intuitive result may be caused in the case of Computers and Office Machinery by high heterogeneity across countries.<sup>1</sup> The hypothesis of different 'national' strategies is confirmed by a regression exercise on selected sub-samples. POLS results on the G5 countries (as in Magnier and Toujas-Bernate, 1994) display a value of estimated  $\gamma$  (at a time lag equal to 3) of 0.28 (significantly positive at the 5% significance level). POLS estimates on the remaining countries do not show a significant statistical relationship between *RDL* and *X*.

This result is undoubtedly related to different national patterns of industrial organisation and efficiency in the connection between research and economic activity and gives an important explicative role to different 'national systems of innovation'. The result for the Chemical industry, in turn, is probably affected by the high product heterogeneity of this sector. It has been calculated as a residual [ISIC: 351(Industrial Chemicals) + 352 (Other Chemicals) - 3522(Pharmaceuticals)] and contains basic industrial chemicals, fertilisers and pesticides, synthetic resins, plastic materials and man-made fibres, paints, varnishes, soaps, perfumes and cosmetics.

The dynamic relation between the relative investment effort indicator (*CFL*) and export market share (*X*) dynamics again shows a highly sector-specific character. At the same time, there is no recognisable pattern in the values of the estimates. The parameters  $\delta$  are significantly positive in the case of Computers and Office Machinery Electrical and Non-electrical Machinery. They are significantly negative in the case of Electrical Machinery and Chemicals.

The estimates of relative labour cost coefficients are significantly positive in three sectors (Aircraft, Non-electrical Machinery and Motor Vehicles), which would support an interpretation in terms of human capital. In these sectors, higher growth of labour costs is associated with improved export performance, and this can reflect the role of skilled labour in sustaining competitiveness.

There is an exception, though. The *RLC* coefficient is negative in Telecommunications Equipment. This latter result is somewhat surprising. As a result, also in this case, POLS regressions have been performed on the sub-sample of the G5 countries and on the sub-sample of the remaining countries. Results confirm what was found by Magnier and Toujas-Bernate (1994): in the regression for the G5 countries, all the parameters  $\varphi$

<sup>1</sup> It is possible that, within the macro-sector considered, there is a variance in sub-products' R&D intensity. Some countries, then, could specialise more than others in sub-products with a high research intensity.

cannot be considered significantly different from zero at a significance level of 10%. At the same time, the negative estimated impact of *RLC* on *X* emerges clearly in the regression analysis for the remaining countries. We must then stress the importance, within diverse sectoral-specific sets of relations, of specific national institutional features and patterns of specialisation, which clearly affect industrial organisation and the determinants of competitive gains.

In sum, our evidence shows that the relationship between countries' relative technological effort and their trade performance is sector specific because the statistical significance and the magnitude of the coefficient vary across sectors. Moreover, the impact of technological variables has different sectoral time lags. This confirms the discussion on the sectoral specificity of the competition process, which is built upon a specific set of technological and institutional conditions which affect the significance and the time structure of the relationships. More work has to be done in order to provide a precise link between the sources of sectoral specificity presented in sub-section 2.2 and the specific sectoral process which links embodied and disembodied technological advancements and success in terms of trade competitiveness.

## 5. Conclusions

The results given in this paper show that the process of technological rivalry between countries in specific industries significantly affects their trade competitiveness in terms of export market shares. Moreover, they show that there are important sectoral patterns in the innovative process and in the relation between technology and world market share dynamics.

The main hypothesis that underpins this paper is that the evolutionary micro-foundations of technological activity and innovation provide a basis for explaining market share dynamics in terms of competition between specific national trajectories (Dosi *et al.*, 1990; Amendola *et al.*, 1993) which, in turn, are affected by the relative amount of investment in R&D and gross fixed capital formation and by specific combinations of the two. At the same time, they help explain why it cannot be assumed that the relationship between technological variables and competitiveness is invariant across sectors.

In particular, this paper has focused on a selected number of OECD countries and manufacturing sectors and shown theoretically and empirically how relative technological efforts in terms of embodied and disembodied technological advancements and their complementarities affect gains in terms of export world shares. The econometric exercise confirms the importance of these technological variables in two ways. First, they are, in general, statistically significant; second, the taxonomy of technological classes in terms of R&D intensity seems to be meaningful in disentangling the role played by sectoral diversity in the relation between embodied and disembodied investment and competitiveness. In particular, a DL specification has been tested in order to evaluate sectoral differences in non-price factors of competitiveness where variables are normalised for the size effect. Relative efforts in R&D (per employee) play a crucial role in affecting world market share dynamics. Sectoral diversity emerges in the statistical significance of the coefficients and in the time lag structure. Moreover, the values of estimated R&D parameters are correlated with the sectoral R&D intensity. This result suggests that R&D intensity is an important cornerstone not only for understanding the technological content of the sectoral activity but also for evaluating the dynamic relation between relative R&D effort and market share dynamics. Important country-specific effects also

emerge. This reveals that important national institutional and organisational forces are at work, as pointed out by the literature on innovation systems.

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### Appendix. The datasets

The following variables are taken from the OECD STAN Databases (Structural Analysis Industrial Database, 1996, 1997): gross fixed capital formation (GFCF: machinery, equipment, buildings, land), labour cost and export. Business enterprise R&D expenses (BERD) come from the OECD ANBERD Databases, Analytical Business Enterprise R&D (OECD, 1996A, 1997A). Official BERD data cover private, public enterprises and institutes serving such enterprises and ‘are based on the sum of performers’ reports on national territory (i.e., excluding payments to international organisations and other performers abroad)’ (OECD, 1998). Problems of international comparability refer to the inclusion of small firms R&D expenses, which are often underestimated, and borderline institutions, which frequently are not allocated to the appropriate manufacturing sector. Moreover, classification problems arise between countries which report on an enterprise basis and countries which report on a product field basis especially when there are big diversified firms. ANBERD tries to overcome these problems opting for the inclusion of ‘service’ firms and industrial research institutes in the manufacture class of the firm they serve and tending to be closer to product field data.

Sectors are displayed in Table A1. Table A2 describes data availability for each sector and country. The choice of the sectors and countries responds to relevance and data availability criteria and guarantees a sufficient degree of diversity in terms of technological content and country characteristics.

**Table A1.** Sectors used in Section 3

Sectors	ISIC Rev.2
Food (food products manufactures: meat, fish, fruits, sugar etc.; beverage: wine, spirits, soft drinks etc.; tobacco manufactures)	31
Textile (wearing apparel, leather, carpet and rugs, furs and footwear)	32
Wood (wood and cork products, furniture)	33
Paper (paper and pulp products, printing and publishing)	34
Chemicals (pharmaceuticals excluded, industrial chemicals, soap, paints, cosmetics)	351+352–3,522
Pharmaceuticals (drugs and medicines)	3,522
Computers and Office Machinery	3,825
Non-electrical Machinery (engines, turbines, agricultural equipment, metal and wood machinery)	382–3,825
Electronics (telecom. equipment semiconductors, TV, radio etc.)	3,832
Electrical Machinery	383–3,832
Motor Vehicles	3,843
Aircraft	3,845

Table A.2. Database used in Section 4

	Aircraft	Electronics	Computers	Pharmaceuticals	Chemicals	Non-electrical	Electrical Machinery	Motor Vehicles	Food	Wood	Paper	Textile	No. sectors	Obs. per country
Aus	-	-	-	-	-	-	-	-	-	-	-	-	11	115
Can	-	-	-	-	-	-	-	-	-	-	-	-	12	125
Den	-	-	-	-	-	-	-	-	-	-	-	-	10	106
Fin	-	-	-	-	-	-	-	-	-	-	-	-	11	111
Fra	-	-	-	-	-	-	-	-	-	-	-	-	12	125
Ger	-	-	-	-	-	-	-	-	-	-	-	-	12	125
Ita	-	-	-	-	-	-	-	-	-	-	-	-	10	105
Jap	-	-	-	-	-	-	-	-	-	-	-	-	11	115
Net	-	-	-	-	-	-	-	-	-	-	-	-	12	125
Nor	-	-	-	-	-	-	-	-	-	-	-	-	11	115
Spa	-	-	-	-	-	-	-	-	-	-	-	-	10	97
Swe	-	-	-	-	-	-	-	-	-	-	-	-	3	36
UK	-	-	-	-	-	-	-	-	-	-	-	-	12	125
US	-	-	-	-	-	-	-	-	-	-	-	-	12	125
Countries (n)	9	13	13	12	12	13	13	12	14	14	13	11		
Years	82-91	82-90	82-90	81-90	81-90	82-90	82-90	82-90	81-91	81-91	77-90	77-90		
T	10	9	9	10	10	9	9	9	11	11	14	14		
n × T	90	117	117	120	120	117	117	108	154	154	182	154		
	No. of observations													
Total	1,550													
High technology	444													
Medium technology	462													
Low technology	644													

