Technology Accumulation and Diffusion

Is There a Regional Dimension?

Pier Carlo Padoan

National patterns of technology diffusion found in country estimates probably reflect sectoral variations more than country variations. They also reflect different degrees of internationalization.

Summary findings

Recently, interest in regionalism has mushroomed, and economists have analyzed it not only from the viewpoint of trade but that of foreign investment, macroeconomics, and political economy. But questions of technological regionalism—whether the accumulation and diffusion of technology has a regional dimension—have been considered only marginally and indirectly.

Padoan offers an exploratory analysis of the regional dimension of technology and diffusion, examining both country and sectoral aspects of it.

Empirical results suggest that regional trade agreements do not necessarily lead to spillover patterns

in regional knowledge. But knowledge may be diffused through vehicles other than trade.

National patterns of technological accumulation seem more important than regional patterns. In particular, more internationalized economies seem capable of commanding a substantial amount of knowledge diffusion, which may sometimes follow regional patterns.

These conclusions are partly confirmed by sectoral estimates that show that regional patterns of knowledge diffusion are highly sector-specific. The knowledge base varies greatly across sectors.

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**TECHNOLOGY ACCUMULATION AND DIFFUSION. IS THERE A
REGIONAL DIMENSION?**

Pier Carlo Padoan , University of Rome "La Sapienza", Rome, College of Europe,
Bruges

Mailing Address

Pier Carlo Padoan

Via Cassia 35, I 00191 Rome, Italy

phone 39 6 8081332

fax 39 6 80687280

email padoan@axcasp.caspur.it

Foreword

As regional trading arrangements (RTAs) have spread, enlarged and deepened over the last decade, they have posed challenges to economists on both intellectual and policy levels. On the former, do RTAs stimulate growth and investment, facilitate technology transfer, shift comparative advantage towards high value-added activities, provide credibility to reform programs, or induce political stability and cooperation? Or do they, on the other hand, divert trade in inefficient directions and undermine the multilateral trading system?

The answer is probably “all of these things, in different proportions according to the particular circumstances of each RTA.” This then poses the policy challenge of how best to manage RTAs in order to get the best balance of benefits and costs. For example, should technical standards be harmonized and, if so, how; do direct or indirect taxes need to be equalized; how should RTAs manage their international trade policies in an outward-looking fashion?

Addressing these issues is one important focus of the research program of the International Trade Division of the World Bank. It has produced a number of methodological innovations in the traditional area of trade effects of RTAs and tackled four new areas of research: the dynamics of regionalism (e.g., convergence, growth, investment, industrial location and migration), deep integration (standards, tax harmonization), regionalism and the rest of the world (including its effects on the multilateral trading system), and certain political economy dimensions of regionalism (e.g., credibility and the use of RTAs as tools of diplomacy).

In addition to thematic work, the program includes a number of studies of specific regional arrangements, conducted in collaboration with the Regional Vice Presidencies of the Bank. Several EU-Mediterranean Association Agreements have been studied and a joint program with the staff of the Latin American and Caribbean Region entitled “**Making the Most of Mercosur**” is under way. Future work is planned on African and Asian regional integration schemes.

Regionalism and Development findings have been and will, in future, be released in a number of outlets. Recent World Bank Policy Research Working Papers concerning these issues include:

Glenn Harrison, Tom Rutherford and David Tarr, “Economic Implications for Turkey of a Customs Union with the European Union,” (WPS 1599, May 1996).

Maurice Schiff, “Small is Beautiful, Preferential Trade Agreements and the Impact of Country Size, Market Share, Efficiency and Trade Policy,” (WPS 1668, October 1996).

L. Alan Winters, “Regionalism versus Multilateralism,” (WPS 1687, November 1996).

Magnus Blomström and Ari Kokko, “How Foreign Investment Affects Host Countries” (WPS1745, March 1997)

Eric Bond, "Using Tariff Indices to Evaluate Preferential Trading Arrangements: An Application to Chile" (WPS1751, April 1997)

Magnus Blomström and Ari Kokko, "Regional Integration and Foreign Direct Investment: A Conceptual Framework and Three Cases" (WPS1750, April 1997)

Glenn Harrison, Thomas Rutherford and David Tarr, "Trade Policy Options for Chile: A Quantitative Evaluation" (forthcoming)

Planned future issues in this series include:

Sherry Stephenson, "Standards, Conformity Assessments and Developing Countries"

Maurice Schiff and L. Alan Winters, "Regional Integration as Diplomacy"

Anthony Venables and Diego Puga, "Trading Arrangements and Industrial Development" (forthcoming)

Other papers on regionalism produced by IECIT include:

Ahmed Galal and Bernard Hoekman (eds), Regional Partners in Global Markets: Limits and Possibilities of the Euro-Med Initiative. CEPR 1997.

Bernard Hoekman and Simeon Djankov, "Imports of Inputs, Foreign Investment and Reorientation of East European Trade," World Bank Economic Review (forthcoming)

Bernard Hoekman and Simeon Djankov, "The EU's Mediterranean Free Trade Initiative," World Economy

Bernard Hoekman and Simeon Djankov, "Effective Protection in Jordan and Egypt in the Transition to Free Trade with Europe," World Development.

Bartłomiej Kaminski, "Establishing Economic Foundations for a Viable State of Bosnia and Hercegovina: Issues and Policies".

In addition, **Making the Most of Mercosur** issued the following papers:

Alexander J. Yeats, "Does Mercosur's Trade Performance Raise Concerns About the Effects of Regional Trade Arrangements?" (WPS1729, February 1997)

Azita Amjadi and L. Alan Winters, "Transport Costs and 'Natural' Integration in Mercosur" (WPS1742, March 1997)

Claudio Frischtak, Danny M. Leipziger and John F. Normand, "Industrial Policy in Mercosur: Issues and Lessons"

Sam Laird (WTO), "Mercosur Trade Policy: Towards Greater Integration"

Margaret Miller and Jerry Caprio, "Empirical Evidence on the Role of Credit for SME Exports in Mercosur"

Malcom Rowat, "Competition Policy within Mercosur"

For copies of these papers or information about these programs contact Maurice Schiff, The World Bank, 1818 H Street NW, Washington, D.C. 20433.

An additional major outlet for World Bank-sponsored research on regionalism will be the Annual Bank Conference on Development in Latin America, 1997, Montevideo, June 30-July 2, 1997, organized by the Office of the Chief Economist and the Technical Department for Latin America and the Caribbean Region, with the support of the International Trade Division and the Economic Development Institute.

Masood Ahmed
Director
International Economics Department

TECHNOLOGY ACCUMULATION AND DIFFUSION. IS THERE A REGIONAL DIMENSION?

Pier Carlo Padoan , University of Rome "La Sapienza", Rome, College of Europe, Bruges*

1.Introduction.

Over the recent past interest in regionalism has mushroomed, looking not only at trade but also at foreign investment, macroeconomic, political economy aspects and implications¹. However, technological regionalism, i.e. whether the process of technology accumulation and diffusion has a regional dimension, has been considered only marginally and indirectly.

The two geographical dimensions of technology accumulation and diffusion usually considered are the global and the national ones. The first one is associated with a situation of complete knowledge diffusion, the second with the case of full national appropriability of the benefits of knowledge accumulation. The national dimension of technology accumulation and diffusion is also considered in the literature on "National Systems of Innovation" (see e.g. Nelson 1993), which also looks at the interaction between globalization of technology and the institutional characteristics of a country's technological activities.

Is a regional dimension of technology accumulation relevant and worth considering? The literature offers few, yet interesting, suggestions. Grossman and Helpman (1991) show that the geographical concentration of knowledge spillovers may be important in affecting long run comparative advantage and specialization. If spillovers are geographically concentrated some countries can deepen and "lock in" their specialization pattern through cumulative processes, given an initial technological lead. Grossman and Helpman (1991) find this to hold theoretically considering national as opposed to global spillovers. However, if spillovers are less than global, these results may hold for geographically limited areas such as regions. Hence specific regions can deepen their specialization and acquire a technological lead.

Breschi and Malerba (1996) study the implications of geographical proximity on the transmission of knowledge according to the characteristics of the knowledge base, itself linked to sector specific characteristics. "The more the knowledge base is tacit, complex, and part of a larger system...the more likely geographical proximity plays a relevant role in facilitating the transmission of knowledge....The more the

* Some of the work contained in this paper was carried out when the author was Visiting Research Fellow at the International Trade Division , The World Bank. An earlier version has been presented at the Annual Meeting of the American Economic Association, New Orleans, January 4-7, 1997. Maurice Schiff has encouraged me to develop the arguments discussed as well as several useful comments on earlier drafts. I would also like to thank Luca De Benedicis, Stefano Manzocchi, Carmen Reinhart, and Alan Winters for many useful suggestions and Marco Ceccagnoli for helpful research assistance. Of course they are not responsible for mistakes and omissions.

¹ Standard references are De Melo and Panagarya (1993) and Anderson and Blackhurst (1993)

relevant knowledge base is codifiable, codified, simple and independent,...the more likely spatial proximity does not play a relevant role in permitting the transfer of relevant knowledge" (p.15)

The rest of this paper offers an exploratory analysis of the regional dimension of technology accumulation and diffusion. Section 2 reviews the existing empirical research on international knowledge flows looking for evidence of a regional dimension. Section 3 provides some evidence of "country aspects" of technological regionalism. Section 4 looks at sectoral aspects. Section 5 concludes and looks at some policy implications.

2. The evidence

While very few studies explicitly address the issue of technological regionalism, several empirical contributions offer some evidence of geographical patterns of innovation diffusion.² In reviewing them it is useful to distinguish between aggregate (i.e. country level) and sectoral aspects.

Country aspects. Ben David and Rahman (1996) look at the issue of convergence in real per capita incomes and find that this is stronger for countries that trade with each other more intensely. Income convergence is related to technological diffusion through trade if one assumes that total factor productivity (TFP) is a proxy for technology. They find support for the hypothesis that trade plays a major role in technology diffusion and that the latter is related to a reduction in the degree of disparities among countries. One implication is that if there is trade regionalism, i.e. trade exhibits regional patterns, there is also some technology regionalism. The trade groups reported by Ben David and Rahman do show some regional aggregation with, e.g. European countries grouped among themselves, Japan grouped with Australia, Korea and the US, and the US grouped with the other countries that show the highest R&D shares (Japan, UK, Germany) as well as with Canada and Mexico.

Similar evidence can be obtained from Coe and Helpman's (1993) calculation of cross countries' elasticities of TFP with respect to R&D capital stocks in the G7 countries. Countries with high elasticities indicate a strong effect of technology diffusion. While the highest elasticities are those with respect to the US, there is also indication of a European regional pattern, with Germany playing the role of regional leader, while Japan holds a similar role for Australia and New Zealand. What these data suggest is that the size of the trading partner is relevant (i.e. smaller countries are more dependent on the foreign stock of R&D than large countries).

Coe, Helpman, and Hoffmeister (1994) extend the previous investigation to developing countries. While the R&D spillovers from the US exhibit the highest TFP elasticities, fast growing East Asian countries show the highest elasticities with respect to Japan and large Mediterranean countries such as Egypt and Turkey show the highest elasticities with respect to Germany.

Regional patterns of technology diffusion related to regional patterns in trade are also found by Bayoumi, Coe and Helpman (1996). They carry out simulation exercises with a multicountry model integrated with the diffusion of R&D stocks

² A recent survey is provided by Mohnen (1996)

through trade, building on previous work by Coe and Helpman (1993) and by Coe, Helpman and Hoffmeister (1994). Not surprisingly, they find a regional pattern of technology diffusion which closely follows regional trade linkages. While there appears to be a strong intra European R&D diffusion effect (especially within continental Europe) European countries as a group do not generate substantial spillovers towards other countries. Also not surprisingly the US appears to be the only large economy to generate substantial R&D spillovers on all other countries.

Nadiri and Kym (1996) carry out a careful analysis of the effects of R&D spillovers on factor demand and on the pattern of trade. They find that the large European countries exchange among themselves a substantial amount of R&D spillovers through imports, with Germany acting as the major net supplier and Italy as the major net beneficiary. Japan and Canada are net beneficiaries as well and the US is a net supplier of technology spillovers among the G7 countries.

Lichtenberg and van Pottelsberghe de la Potterie (1996) provide evidence on the role of outward foreign direct investments (FDI) as vehicles of technology sourcing. The hypothesis they test is that firms locate FDI in technology intensive countries in order to benefit directly from local innovation spillovers. When measuring output elasticities of domestic R&D capital stocks to outward FDI flows the evidence of regional patterns is much more limited; indeed in almost all bilateral relationships investment in the US dominates investment in other countries as a source of technology diffusion. Some regional effects can be found in small European countries with respect to investment in the UK. This evidence is consistent with the view that, along with regional patterns of the organization of trade, an increasing process of globalization of markets through FDI is taking place, especially among the OECD countries (Reinicke 1996).

The above results suggest a regional effect of technology diffusion linked to trade flows. The question then arises as to whether these effects are determined by the same factors which shape regional trade patterns. Here the evidence is still very limited. Sjöholm (1996) looks at the role of geographical proximity and international trade in the international transfer of knowledge in the case of Sweden. Geographical proximity may be important to the extent that knowledge spreads through informal contacts and these may be limited by distance, as Breschi and Malerba (1996) also find. Distance is found to be related to technology transfers measured by the number of patent citations. However, an extreme bound analysis finds that only trade is a robust explanation of technology transfers.

Baldwin and Seghezza (1996) consider the effect of regional agreements on growth induced by technology accumulation: i.e. they look at the reverse causality between regional patterns and technology with respect to the literature reviewed above. They find “weak evidence that EU membership allowed member states to enjoy a higher level of (TFP) ... than they would have otherwise. In other words EU membership led to knowledge-led growth effects” (p.18)

In the above studies technology is measured directly through cumulated R&D expenditure or indirectly through TFP. Archibugi and Pianta (1992, 1994) look at technological convergence using indicators of technological activity such as R&D/GDP and patents/exports. They find that production in advanced countries has become more technology intensive over the last two decades while the group of countries capable of innovating at the frontier of technological specialization has widened. However, they also report increasing divergence among the group of top R&D investors. Finally, they find that size is important in defining the direction of

technology diffusion (from large to small countries) not just because smaller countries are, on average, more open to imports than large ones, but also because of differences in the spectrum of specialization.

Sectoral aspects This last point leads us to the issue of the relationship between aggregate outcomes and sectoral determinants. Some authors (Dollar and Wolff 1993) have suggested that increases in TFP are the results of sectoral performance: i.e. aggregate results “hide” sector specific behavior in the sense that convergence in TFP is associated with increasing sectoral specialization. If, in addition, productivity changes are the result of technology accumulation, knowledge is, to a large extent, sector specific. This could be reflected in its geographical diffusion patterns, i.e. while one does not need to observe a general tendency towards technological regionalism this may be present at sectoral levels.

Evidence on international technology specialization (Archibugi and Pianta 1992, 1994) shows that there are important differences between small and large countries. The former specialize only in a limited number of sectors, while no large country (not even the US) enjoys leadership in all technology intensive sectors. A regional pattern of technology diffusion assumes a hierarchical structure in the sense that, on the one hand, diffusion may take a regional dimension, on the other hand smaller countries in the region specialize only in a limited number of sectors in which the region as a whole is specialized.

Looking at technological specialization -measured by sectoral distribution of patents- Archibugi and Pianta introduce a measure of technological distance between pairs of countries, i.e. a measure of similarity between patterns of technological specialization. In this case too, not surprisingly, country size is quite relevant. Larger countries are more similar with one another because they spread technological innovation (as measured by patents) across more sectors, i.e. they are less specialized. Smaller countries are more specialized and they also tend to be technologically closer to the larger country which shares the same sectoral specialization. This pattern can be found also in trade and production specialization (Dollar and Wolff 1993).

The introduction of sectoral aspects leads to a more varied pattern of technological relations. Archibugi and Pianta show that within Europe, France and the UK are more similar to the US (which is also very similar to Canada), Germany is more similar to Italy and is closer to France and the UK than it is to the US, while its distance from Japan is the highest among the large countries. Italy is close only to Germany and quite distant from the other large EU countries. Spain is close to Germany and Italy and far from the US. Smaller countries such as Belgium and the Netherlands are closer to the UK and France than to Germany. In general, these results suggest that Europe is not an homogeneous technological region. This is consistent also with the results of Caballero and Lyons (1992) who find only weak evidence of sectoral and national externalities among the large European countries. Finally, Japan shows clearly distinct features and is distant from almost every other country.

Results by OECD (1996) also suggest that regional patterns, in the sense of technology flows through trade associated with geographical proximity, are sector specific rather than country specific, i.e. smaller countries acquire embodied technology from large countries that vary according to the sector involved. Italy acquires technology from the US in the computers sector and from Germany in

communication equipment, the Netherlands acquires technology from the US in aerospace and computers and from Germany in electrical machinery.

Evidence offered by Breschi and Malerba (1996) also suggests that geographical patterns of technology diffusion vary across sectors because their knowledge base, i.e. whether tacit or codifiable, differs, and so -depending on the sector- geographical proximity may be either highly relevant or indifferent.

In conclusion, a number of overlapping patterns emerge: a) when technology flows are closely associated with trade flows a regional and hierarchical pattern appears as technology flows are more important from large to small countries than viceversa; however, this is clearly the consequence of limiting the analysis to trade as a vehicle of knowledge as this pattern reflects aggregate trade flows (since smaller countries import proportionally more than large countries); b) when vehicles of technology diffusion other than trade, such as FDI, are considered, regional patterns seem to be replaced by a more global pattern where the US is the major source of technology diffusion; c) smaller countries show higher technological specialization than large countries and their technological distance varies by sector, which hints at the relevance of sector specific knowledge flows. In this latter case, too, regional patterns are more difficult to detect.

The evidence discussed above, while encouraging a further examination of the regional dimensions of technology diffusion, does not consider two other closely related issues. One is that any amount of technology diffusion implies a proportion of technology accumulation in the country that receives the new technology in order for the latter to be adapted to the characteristics of the domestic economy. Absorption of foreign technology always implies an amount of domestic knowledge production (Bell and Pavitt 1995), hence, if technology diffusion follows a regional pattern, this should be reflected, at least partially, in the domestic (national) knowledge production process.

The second is that the evidence on regional patterns of technological specialization suggests that regional leaders (large countries) are specialized in a relatively large number of sectors while small countries are specialized only in some sectors. However regional leaders are not specialized in all sectors. Hence, if there are sector specific regional patterns, small countries in one region should be specialized in sectors where also the regional leaders are specialized, although this may depend on the characteristics of the knowledge base. This calls into question the relationship between trade and technological specialization: i.e. to what extent geographical patterns of technological linkages influence, and are related to, the pattern of trade and production specialization.

The next two sections in considering the two aspects above, offer exploratory analyses of geographical patterns of technology accumulation and diffusion, taking into account, at the country level, different vehicles of knowledge diffusion.

3. Country Aspects

In this section we provide some preliminary tests of the hypothesis that national patterns of technological accumulation and diffusion are influenced by the absorption of foreign knowledge through a regional, as opposed to global, pattern.

We concentrate the analysis on four large European countries, Germany, France, Italy and the UK, and on Japan. The analysis of the European countries is justified by the fact that we consider members of a well established regional agreement for which data on technology accumulation and diffusion are available. So we take into account the effects of both geographical proximity and institutional arrangements on technology accumulation and diffusion. Japan represents a case of an highly advanced economy yet not belonging to a specific trade agreement so that possible regional links are to be related to geographical links (with the US economy) rather than institutional determinants.

We estimate an equation of knowledge accumulation -eq (5) below³- embedded in a model of trade specialization and growth (Padoan 1996), in order to capture the relationships between trade specialization and knowledge accumulation⁴.

The logic of the model may be quickly summarized as follows. Consider an economy where firms engage in R&D activities to accumulate knowledge and increase their market shares both in domestic and foreign markets. Goods are differentiated with respect to the relevance of knowledge in determining their demand, which also depends on relative prices. As Maquier and Tojas-Bernate (1994) suggest, the stock of knowledge determines, in a framework of imperfect competition, the non price (quality) determinants of consumers' demand and relative shares in the international market. More specifically, we may assume that the stock of knowledge is a proxy for variety. However, quality influences demand with different intensity across sectors; this is captured by different knowledge elasticities⁵.

In the model we follow Pavitt's (1984) taxonomy to group manufacturing goods into four macrosectors. In this taxonomy⁶ manufacturing sectors are grouped according to the position each sector holds in the process of knowledge accumulation and diffusion, as well as on the role of knowledge and of other factors in determining performance. Thus this taxonomy, in addition to being quite suitable for the analysis of the interaction between trade and knowledge accumulation, has the advantage of providing an empirical classification of manufacturing sectors.

The estimates of parameters of eq. (5) reported in tables 1-5 are the result of the (FIML) estimation of the model described in Appendix 1 where some details about the estimation procedure as well as continuous time econometrics are reported.

$$D \log T = \alpha_6 (\log T^* - \log T) + \sigma_1 \log T_{F1} + \sigma_2 \log T_{F2} + \sigma_3 \log S_{MH1} + \sigma_4 \log S_{MH2} \quad (5)$$

$$\log T^* = \log \gamma_5 + \sigma_5 \log F + \sigma_6 \log S_D$$

Eq (5) describes knowledge accumulation in the economy as a continuous time disequilibrium process, where the output of the knowledge production process is represented by patents. The (log of) the endogenous variable T adjusts to its (partial) equilibrium value T^* . We assume that, while there are different sectors in the

³ The numbering of equation (5) follows the numbering adopted in the full model described in Appendix 1

⁴ The ambivalent relationship between trade and technology is discussed in Padoan (1996)

⁵ Amable and Verspagen (1995) find that export shares of goods belonging to different Pavitt macrosectors present different elasticities with respect to prices and technology indicators. This is also found in Padoan (1996).

⁶ See the Appendix 1 for more details.

economy, the knowledge production process is one and country specific, i.e. that the pool of domestic knowledge is equally accessible to all sectors.⁷

In an open economy two aspects of the process of knowledge accumulation must be considered, one is related to domestic factors, the other is related to foreign factors affecting knowledge accumulation. Both are relevant since, as mentioned above, absorption of foreign knowledge always requires some form and amount of domestic knowledge production, i.e. domestic and foreign innovative efforts are, to some extent, complementary inputs in the process of domestic knowledge accumulation.

More specifically, the idea behind eq. (5) is the following. The accumulation of the stock of domestic knowledge T is basically determined by a domestic effort, i.e. the partial equilibrium level of T ⁸ is a function of domestic variables, the domestic stock of R&D expenditure, F , and the “size” of the science based sector in the economy, proxied by its export market share S_D ⁹. The rationale for F is obviously that R&D represents the most important input in the knowledge production process. The rationale for the second variable is that, according to Pavitt’s taxonomy, the science based sector generates an externality in the domestic knowledge production process.

The four foreign variables entering equation (5), the stocks of foreign knowledge T_{F1} , T_{F2} and the shares of high tech imports S_{MH1} , S_{MH2} ¹⁰, do not determine directly the partial equilibrium level of T , rather one can think of eq. (5) as being a linear approximation of a non linear form where the adjustment speed α_6 is a function of foreign knowledge variables, i.e. $\alpha_6 = \phi(T_{Fi}, S_{MHi})$. Such a formulation implies that the absorption of foreign knowledge, the intensity of which may be thought of being a function of what Abramovitz calls “social capability”¹¹ (captured by parameters σ_i , $i=1,...,4$), increases the speed of the process of domestic knowledge accumulation. The reason why two different kinds of foreign knowledge variables are included is that the channels of international knowledge diffusion are several (indeed more than two) as we have seen in the previous section¹². The stocks of foreign knowledge, T_F can be thought of as a proxy of sources of knowledge diffusion other than imports.

The hypothesis of regional effects in knowledge diffusion has been tested by disaggregating the share of world imports of high tech goods and the foreign stock of knowledge in two components, a “regional” component, denoted with subscript 1, and a “non regional” component denoted with subscript 2. Regional variables are

⁷ A more satisfactory approach would be to model sector specific as well as country specific knowledge accumulation processes and study their interaction. We leave this for future research.

⁸ We define T^* as the partial equilibrium level of domestic knowledge as it is determined assuming that the values of the other endogenous variables entering the model, described in Appendix 1, are given.

⁹ The size of the science based sector should be proxied by the share of domestic production in the sector or, alternatively, by the share of science based exports in total domestic exports, rather than by S_D . Model parsimony in the first case and irrelevant differences in estimation in the second case suggested the use of S_D , allowing to gain something in analytical and empirical handling, see Padoan (1996).

¹⁰ As Keller (1995, 1996) suggests not all imports, but only imports of intermediate goods, are vehicles of technology diffusion. In the context of Pavitt’s taxonomy this role is played by the aggregate we have defined as high tech imports, see Appendix 1.

¹¹ See Abramovitz (1986) and Ben-David and Loewy (1995).

¹² For the case of developing countries see Freeman and Hagedoorn (1994).

European¹³ for the four European cases and US variables for Japan. Non regional variables are, non European and non US variables respectively.

Tables (1)-(5) report the estimated versions of eq. (5). We estimate several versions of eq. (5), proceeding in steps. We first consider the two sources of foreign knowledge separately, testing for differences in the associated parameters. We then try combinations of the two sources of foreign knowledge allowing for the presence of different geographical effects according to the different source of foreign knowledge (e.g. regional effects may be present or relevant when imports are the vehicle of knowledge but may be negligible when other vehicles, as captured by the stock of foreign knowledge, are considered). We finally test for the effect of each of the four foreign knowledge variables separately to assess their individual contribution to domestic knowledge accumulation. We assume the presence of "strong" regional effects when only regional foreign knowledge affects significantly domestic knowledge accumulation. A "weak" regional effect is assumed when both regional and non regional foreign knowledge affects domestic knowledge accumulation, but the former exerts a stronger effect. Tables (1)- (5) report parameter estimates (standard error in parenthesis) as well as tests for the differences of parameters σ_1, σ_2 and σ_3, σ_4 , respectively when appropriate. CNR^2 is the Carter Nagar statistics for simultaneous models, see Carter, Nagar (1977). The latter values refer to the FIML estimation of the full model described in Appendix 1.

Discussion is best carried out on a country by country case.

Germany -see table 1- is the only case that shows strong regional effects. The parameter σ_1 is larger than σ_2 , which is also non significant (case 1). The same is true when high tech imports are included in place of the stock of knowledge. This result is confirmed by case (3) where only European variables are included. The case where only non European variables are included presents mostly non significant variables and is not reported. Estimates with only one foreign variable -cases (4)-(7)- suggest that high tech imports rather than the foreign stock of knowledge, capture the foreign spillover effect, consistently with results obtained in Padoan (1996).

France This case -see table 2- exhibits weak regional effects. Both stocks of foreign knowledge are significant but the parameter σ_1 is significantly larger than σ_2 -case (1). The opposite holds, however, when imports of high tech goods are considered. While both variables are significant, non European high tech imports show a significantly larger parameter with respect to the European high tech imports, see case (2). Regional effects, therefore, seem to depend on the vehicle of knowledge diffusion. This is confirmed by case (4) which includes both stocks of foreign knowledge and non European high tech imports, and which shows the highest CNR^2 value. Versions with only one foreign variables -cases (7)-(10)- confirm the results above. The European stock of knowledge and the non European high tech imports show the best results in terms of parameter values and goodness of fit.

The case of *Italy*, see table 3, should be classified as one showing weak regional effects, nevertheless such effects appear stronger than the case of France. The parameter σ_1 is significantly larger than σ_2 , case (1), and the same applies when high tech imports are considered, case (2). The best fit is obtained when both stocks of

¹³ Each time defined so as to exclude the country under investigation. See Appendix 2

knowledge as well as high tech imports are included, case (3). However, in such a case, both σ_1 and σ_2 are not significant. Case (5), which includes T_E and S_{MHE} , confirms these results. The strong relevance of high tech imports as vehicles of knowledge diffusion is confirmed in cases (6)-(9). This reinforces the impression that the regional effect of knowledge diffusion works mainly through imports rather than through other vehicles, as already found in Padoan (1996).

The case of the *UK*, see table 4, presents rather weak regional effects and suggests that the role of foreign knowledge is much more relevant than that of high tech imports in knowledge diffusion. The value of σ_1 -see case (1)- is significantly larger than that of σ_2 . The same applies for high tech imports -see case (2)- but the associated elasticities are smaller and so is the adjustment speed. The goodness of fit is also less satisfactory. These results are confirmed by the other cases. Estimates including only one foreign variable, cases (7)-(10), confirm the results above. The *UK* is the only country case where all foreign variables, when included individually in the equation, are significant. This suggests that the pattern of foreign knowledge diffusion for the *UK* economy is both global (i.e. not strictly regional) and associated with different vehicles.

Japan exhibits “regional” effects in technology diffusion, see table 5, in its linkages with the United States. However these are limited to the role of high tech imports as the stocks of foreign knowledge, both US and non US, are never significant, in accordance with results obtained in Padoan (1996). The point estimate of σ_3 is significantly higher than that of σ_4 , case (2). This is confirmed by the cases including only one foreign variable -cases (5)-(8)- where the cases including high tech imports from the US shows the best goodness of fit.

In conclusion, all countries show some regional effects of technology diffusion, although only Germany shows what we have defined a strong regional effect. It is interesting to note that, in the cases of France and the *UK*, regional effects are working through the foreign (European) stock of knowledge and not through high tech imports. Results for Germany and Italy, however, suggest that imports of high tech goods, rather than, or in addition to, other vehicles of knowledge diffusion reveal a regional pattern. The case of *Japan* also supports the role of trade as a vehicle of knowledge diffusion. Our evidence suggests that regional trade linkages represent only partially a factor of technological regionalism, a result partly at odds with those reported in the literature reviewed above. On the other hand, our results also support the view that vehicles of knowledge diffusion other than trade are relevant in regional linkages, a result that is not usually found in the literature.

4. Sectoral aspects

In this section we consider sectoral aspects of technological diffusion in order to test whether technological specialization and diffusion is sector specific and whether the results obtained at the aggregate level hide a sectoral dimension. To this purpose we estimate a simple model which links trade and production specialization to technological specialization.

The theoretical underpinnings of the relationship between trade, production and technological specialization are still to be completely developed, yet a number of elements may be singled out: a) we know from “New Trade Theory” (see e.g. Venables 1995, Krugman and Venables 1996) that, as barriers and other impediments to trade decrease, production (and trade) specialization deepens, especially in sectors that exhibit increasing returns; b) trade and production specialization interact with technological specialization, leading to cumulative effects and “lock in” phenomena (Lucas 1988); c) specialization patterns, both in technology and in production and trade, tend to change slowly over time. This is especially true of Europe (Cantwell 1989, Amendola, Guerrieri, Padoan 1992); d) large countries are less specialized than small countries, both in production and in technology (Dollar and Wolff 1993, Archibugi, Pianta 1994); e) the extent of technology diffusion varies greatly across sectors (Dollar and Wolff 1993, Breschi and Malerba 1996); f) as discussed in the previous section, technological accumulation is the result of both domestic and foreign efforts, hence one should detect a correlation between domestic and foreign technological specialization.

The descriptive continuous time model below tries to capture the elements listed above and, in particular, looks at the issue of whether the relevant foreign technological specialization is located within or outside the region under consideration.

$$\begin{aligned} D\log IPS &= \delta_1 (\log IPS^* - \log IPS) \\ \log IPS^* &= \log \varphi_1 + \eta_1 \log IES \end{aligned} \quad (2.1)$$

$$\begin{aligned} D\log IES &= \delta_2 (\log IES^* - \log IES) \\ \log IES^* &= \log \varphi_2 + \eta_2 \log ITS \end{aligned} \quad (2.2)$$

$$\begin{aligned} D\log ITS &= \delta_3 (\log ITS^* - \log ITS) \\ \log ITS^* &= \log \varphi_3 + \eta_3 \log IPS + \eta_4 \log ITSF \end{aligned} \quad (2.3)$$

or, alternatively

$$\log ITS^* = \log \varphi_3 + \eta_3 \log IPS + \eta_5 \log ITSE$$

Eq. (2.1) says that production specialization in the sector considered, *IPS*, adjusts to a partial equilibrium value *IPS**, which is positively related to export specialization *IES*, in the same sector. Export specialization, in turn, adjusts -eq. (2.2) - to technological specialization *ITS*, which is itself adjusting -eq. (2.3) - to both domestic production specialization and to an exogenous index of foreign technological specialization. In the first version *ITSF* refers to US technological specialization, in the second version *ITSE* refers to European specialization. As above, *D* indicates the derivative with respect to time.

Model (2.1) - (2.3) has been estimated with simultaneous methods (FIML) for six sectors - aerospace, chemical products (excluding drugs), electrical and electronics, mechanical equipment, motor vehicles, textiles- characterized by different features and degrees of technological intensity and innovation activity and by a different knowledge base. The latter is captured by the index *ITS* (see Appendix 2 for details) which takes into account both R&D and patenting activity in each sector. The sectors chosen differ substantially with respect to market structure and the presence

of technological barriers (Archibugi and Pianta 1992, Breschi and Malerba 1996). Aerospace, chemicals and electrical and electronics present high barriers to entry in technological investment but also global knowledge boundaries; motor vehicles feature few innovators that are also geographically concentrated with local knowledge boundaries; mechanical equipment presents strong cumulative features in technological accumulation, but also many innovators geographically concentrated with local knowledge boundaries; finally, textiles present high pervasiveness in technological accumulation and diffusion as the many innovators are geographically dispersed with no specific knowledge spatial boundaries.¹⁴ A priori one should expect stronger regional and cumulative effects in motor vehicles and mechanical equipment, and less so in the other sectors.

Results of the estimation of model (2.1)-(2.3) are reported in tables 6-11. We omit discussion of the full results and concentrate on the linkages between domestic and foreign technological specialization, i.e. the estimates of parameters η_4 and η_5 . We consider results by sector confronting different country behavior. Case 1 refers to the version with *ITSF* (US technological specialization), case 2 refers to the version with *ITSE* (European technological specialization). The estimates for Japan refer only to the first case. CNR^2 is the Carter Nagar statistics for simultaneous models, see Carter, Nagar (1977).

Textiles In three European cases, Germany, France and Italy -see table 6- domestic technological specialization is highly correlated to US rather than to European technological specialization. With the exception of the UK, European technological specialization does not seem to exert any significant effect. The case of Japan suggests a strong effect of US technological specialization on domestic technological specialization. In general results seem to confirm the pervasive nature of technology in this sector.

Motor Vehicles Results for the four European countries -see table 7- suggest a strong influence of European technological specialization on domestic technological specialization. This supports the assumption of few innovators that are also geographically concentrated with local knowledge boundaries. Significant estimates of η_3 , the elasticity of technological specialization with respect to production specialization, confirm the presence of a cumulative interaction between production and innovation activities. Geographical concentration also appears in the case of Japan where foreign (US) technological specialization does not significantly affect domestic technological specialization.

Electrical and electronics Regional (European) technological specialization -see table 8- influences domestic technological specialization in the cases of Germany, France and the UK. In the latter two cases significant estimates of η_3 , the elasticity of technological specialization with respect to production specialization, confirm the presence of a cumulative interaction between production and innovation activities. In the case of the UK, however, US technological specialization apparently exerts a

¹⁴ With respect to Pavitt's taxonomy, adopted in the previous section, aerospace, electrical and electronics as well as chemical products are science based sectors, motor vehicles are scale intensive, mechanical equipment are specialized suppliers and textiles are traditional products.

stronger effect, suggesting global rather than local knowledge boundaries. Finally, no effect of foreign specialization can be found in the cases of Japan and Italy.

Chemicals As expected, the chemical industry does not show any significant effect of regional technological specialization on domestic technological specialization -see table 9. The case of Germany shows that domestic technological specialization is strongly related to US technological specialization. In this case the point estimate of η_3 , the elasticity of technological specialization with respect to production specialization, confirms the presence of a cumulative interaction between production and innovation activities.

Mechanical Equipment The US specialization index -see table 10- apparently influences domestic technological specialization in Germany, France and the UK, as well as in Japan. European specialization is also important in the case of Germany. In several cases strong cumulative interaction with technological specialization is present.

Aerospace US specialization -see table 11- produces a significant influence on domestic specialization in the cases of France and Germany, however European specialization is important in the case of Germany. The estimates for Italy improve dramatically when the European, rather than US, specialization index is included.

In general, estimates support the view that regional effects on technological specialization are sector specific, i.e. some sectors show some regional patterns while these are totally absent in others. Within sectors country patterns are also different and they confirm some of the country results discussed in the previous section. However the a priori expectations about specific sectors' behavior are only partially confirmed.

5. Conclusions and policy implications

In this paper we have looked for the presence of a regional dimension of technology accumulation and diffusion both at the country and at the sectoral level. Our estimates yield mixed results that are summarized in table 12

Table 12. Summary of results

	Germ.	France	Italy	UK	Japan
Country	XX	X	X	X	X
Textiles				X	XX
Mot. V..	XX	XX	XX	XX	
Aeros.	X		XX		
Chem					
Electr.	XX	XX		X	
Mechan.	X				XX

X= weak regional effect, XX= strong regional effect

Germany, and to a lesser extent Italy, show stronger regional effects both at the country and at the sectoral levels. France and the United Kingdom show weak

regional effects at the country level and stronger effects at the sectoral level in the case of motor vehicles, which appears to be the most highly regionalized sector, followed by the electrical and electronic machinery. Interestingly, these two sectors also show a relatively strong interaction between production and technology specialization. As sectoral estimates show, cumulative effects are particularly relevant in chemicals, aerospace and mechanical equipment where regional effects are weak or totally absent. Finally, Japan shows relevant regional links with the US. One point to be stressed is that country effects differ somewhat according to the variable that is used to capture the presence of regional technology patterns, i.e. such patterns may be associated with stocks of knowledge and much less so when high tech imports are considered (as in the cases of France, the UK and Japan).

These results point to the fact that regional trade agreements do not necessarily lead to regional knowledge spillover patterns as much as the literature seems to suggest, at least indirectly. Regional patterns, however, may be present through vehicles of knowledge diffusion other than trade. These conclusions are also partially confirmed by our sectoral estimates, that show that regional patterns of knowledge diffusion are highly sector specific as the knowledge base varies greatly across sectors. National differences in the role of vehicles of diffusion found in the country estimates possibly reflect sectoral rather than national features, as well as different degrees of internationalization of the national economies. These results could also partially explain the puzzle that countries belonging to the same regional agreement (the EU) show different degrees of technology regionalism.

Some general policy implications may be drawn from our results. Preferential trade agreements do not necessarily lead to benefits to their members in terms of stronger technology diffusion. Rather, national patterns of technological accumulation seem to prevail over the regional dimension. In particular, economies showing a high degree of internationalization seem capable of commanding a substantial amount of knowledge diffusion which may sometimes follow regional patterns. One implication is that policies should be developed that strengthen the degree of internationalization of national systems of innovation.

Our results, however, also show strong sectoral effects in regional patterns of technology diffusion. This may be related to linkages between production and technological specialization that are specific to a region. In other cases however -as the results for the motor vehicle sector show- both regions considered, the US and the EU, are strongly specialized in the same sector and yet regional technological effects are present. This apparent contradiction may be explained by the fact that sector specific barriers, such as NTB, standards, local content clauses etc., affect the regional pattern of knowledge diffusion through their effects on trade and international investment decisions. These results suggest that measures affecting markets access may lead to relevant consequences on the extension, and possibly the intensity, of knowledge accumulation and diffusion.

Much further work is needed, both at the theoretical and the empirical level, to establish a clear picture of the geographical patterns of technological accumulation and diffusion. In particular, the relationship between sectoral and country aspects should be further clarified. The preliminary evidence presented here supports the view that different elements -national, regional and global- coexist in the geography of technology accumulation and diffusion. Several policy implications may follow, but not necessarily that regional trade agreements lead to additional benefits in terms of knowledge diffusion.

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Table 1 Germany. Point estimates. Asymptotic standard errors in parenthesis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
α_6	0.087 (0.034)	0.012 (0.004)	0.238 (0.101)	0.282 (0.123)	0.174 (0.089)	0.233 (0.054)	0.067 (0.023)
σ_1	0.012 (0.004)		0.010 (0.004)	0.076 (0.054)			
σ_2	0.009 (0.014)				0.006 (0.010)		
σ_3		0.024 (0.012)	0.011 (0.004)			0.016 (0.005)	
σ_4		0.005 (0.011)					0.009 (0.007)
σ_5	0.034 (0.015)	0.064 (0.041)	0.588 (0.184)	0.424 (0.211)	0.549 (0.174)	0.591 (0.054)	0.249 (0.543)
σ_6	0.012 (0.004)	0.034 (0.012)	0.108 (0.005)	0.049 (0.021)	0.071 (0.033)	0.108 (0.022)	0.091 (0.124)
$\sigma_1-\sigma_2$	0.003 (0.001)						
$\sigma_3-\sigma_4$		0.017 (0.005)					
CNR ²	0.209	0.544	0.693	0.612	0.618	0.693	0.054

Table 2. France. Point estimates. Asymptotic standard errors in parenthesis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
α_6	0.931 (0.138)	0.016 (0.875)	0.789 (0.106)	0.824 (0.148)	0.061 (0.100)	0.041 (0.020)	0.049 (0.025)	0.035 (0.009)	0.041 (0.019)	0.011 (0.002)
σ_1	0.511 (0.077)		0.478 (0.064)	0.762 (0.139)	0.310 (0.019)		0.381 (0.103)			
σ_2	0.416 (0.070)		0.371 (0.066)	0.655 (0.124)		0.015 (0.051)		0.043 (0.025)		
σ_3		0.090 (0.015)	0.060 (0.022)		0.009 (0.007)				0.066 (0.024)	
σ_4		0.104 (0.025)		0.047 (0.013)		0.043 (0.019)				0.090 (0.017)
σ_5	0.116 (0.007)	0.202 (0.301)	0.109 (0.008)	0.080 (0.007)	0.018 (0.010)	0.041 (0.031)	0.146 (0.051)	0.058 (0.022)	0.057 (0.002)	0.042 (0.005)
σ_6	0.037 (0.005)	0.225 (0.324)	0.031 (0.005)	0.028 (0.003)	0.054 (0.080)	0.165 (0.151)	0.219 (0.115)	0.129 (0.031)	0.172 (0.136)	0.127 (0.006)
$\sigma_1 - \sigma_2$	0.095 (0.019)		0.107 (0.018)	0.107 (0.023)						
$\sigma_3 - \sigma_4$		-0.014 (0.005)								
CN R ²	0.857	0.125	0.869	0.885	0.210	0.270	0.672	0.646	0.606	0.646

Table 3. Italy. Point estimates. Asymptotic standard errors in parenthesis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
α_6	0.113 (0.040)	0.052 (0.015)	0.166 (0.037)	0.072 (0.514)	0.098 (0.047)	0.135 (0.042)	0.072 (0.024)	0.051 (0.035)	0.074 (0.018)
σ_1	0.789 (0.323)		0.211 (0.214)	0.327 (1.131)	0.0358 (0.059)	0.049 (0.054)			
σ_2	0.129 (0.052)		0.081 (0.061)	0.280 (0.355)			0.047 (0.071)		
σ_3		0.017 (0.003)	0.016 (0.002)		0.004 (0.002)			0.0178 (0.002)	
σ_4		0.0014 (0.006)		0.127 (0.033)					0.016 (0.005)
σ_5	0.224 (0.088)	0.535 (0.040)	0.480 (0.229)	0.180 (0.251)	0.163 (0.231)	0.761 (0.391)	0.988 (0.761)	0.539 (0.021)	0.564 (0.029)
σ_6	0.022 (0.027)	0.825 (0.029)	0.349 (0.331)	0.161 (0.772)	0.103 (0.158)	0.187 (0.159)	0.287 (0.237)	0.881 (0.304)	0.302 (0.117)
$\sigma_1 - \sigma_2$	0.680 (0.277)		0.139 (0.104)	0.047 (0.013)					
$\sigma_3 - \sigma_4$		0.0155 (0.006)							
CN R ²	0.566	0.724	0.723	0.165	0.177	0.176	0.503	0.734	0.611

Table 4 UK. Point estimates. Asymptotic standard errors in parenthesis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
α_6	3.223 (0.931)	0.090 (0.041)	2.258 (0.304)	3.026 (0.866)	1.038 (0.108)	0.681 (0.210)	1.006 (0.187)	0.393 (0.198)	0.091 (0.021)	0.065 (0.032)
σ_1	1.739 (0.463)		1.482 (0.171)	1.577 (0.436)	0.941 (0.105)			0.840 (0.173)		
σ_2	1.242 (0.458)		0.646 (0.143)	1.243 (0.433)		0.668 (0.213)		0.255 (0.141)		
σ_3		0.016 (0.004)	0.012 (0.006)		0.0242 (0.002)				0.013 (0.003)	
σ_4		0.037 (0.009)		0.031 (0.003)		0.046 (0.011)				0.019 (0.008)
σ_5	0.025 (0.002)	0.639 (0.225)	0.033 (0.005)	0.031 (0.15)	0.007 (0.001)	0.075 (0.024)	0.034 (0.019)	0.167 (0.056)	0.663 (0.018)	0.543 (0.070)
σ_6	0.020 (0.010)	0.064 (0.033)	0.021 (0.009)	0.033 (0.001)	0.011 (0.001)	0.099 (0.003)	0.006 (0.002)	0.001 (0.007)	0.075 (0.023)	0.047 (0.029)
$\sigma_1-\sigma_2$	0.497 (0.253)		0.835 (0.114)	0.333 (0.158)						
$\sigma_3-\sigma_4$		0.021 (0.004)								
CN R ²	0.689	0.424	0.695	0.893	0.639	0.617	0.639	0.501	0.571	0.555

Table 5 Japan. Point estimates. Asymptotic standard errors in parenthesis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
α_6	0.063 (0.008)	0.020 (0.004)	0.053 (0.006)	0.019 (0.006)	0.090 (0.031)	0.086 (0.023)	0.016 (0.002)	0.007 (0.004)
σ_1	0.016 (0.047)		0.009 (0.012)	0.012 (0.014)	0.013 (0.068)			
σ_2	0.032 (0.475)		0.002 (0.042)			0.004 (0.093)		
σ_3		0.048 (0.022)	0.016 (0.008)	0.027 (0.010)			0.029 (0.008)	
σ_4		0.022 (0.016)						0.015 (0.007)
σ_5	0.163 (0.019)	0.527 (0.172)	0.129 (0.078)	0.156 (0.369)	0.107 (0.091)	0.083 (0.039)	0.072 (0.012)	0.004 (0.002)
σ_6	0.080 (0.021)	0.236 (0.087)	0.074 (0.028)	0.701 (0.036)	0.221 (0.058)	0.209 (0.117)	0.122 (0.058)	0.115 (0.049)
$\sigma_1 - \sigma_2$	-0.016 (0.033)		0.007 (0.012)					
$\sigma_3 - \sigma_4$		0.026 (0.011)						
CN R ²	0.202	0.285	0.307	0.248	0.197	0.217	0.223	0.188

Table 6: Point estimates. Textiles . Asymptotic standard errors in parenthesis

	δ_1	δ_2	δ_3	η_1	η_2	η_3	η_4	η_5	CNR^2
Germ 1	0.659 (0.237)	0.104 (0.267)	4.224 (1.861)	0.352 (0.141)	0.439 (0.954)	1.668 (0.779)	1.064 (0.432)		0.5266
Germ 2	0.833 (0.410)	0.075 (0.241)	3.329 (1.461)	0.441 (0.195)	0.674 (1.605)	3.127 (0.816)		0.004 (0.008)	0.4551
Fran 1	0.477 (0.169)	0.302 (0.118)	3.022 (1.291)	0.242 (0.237)	0.200 (0.465)	0.873 (0.847)	1.686 (0.648)		0.5559
Fran 2	0.488 (0.172)	0.295 (0.129)	2.830 (1.422)	0.231 (0.224)	0.154 (0.513)	0.325 (1.301)		0.025 (0.147)	0.4054
UK 1	0.389 (0.165)	0.549 (0.284)	0.376 (0.176)	0.294 (0.414)	0.118 (0.102)	0.012 (0.132)	2.947 (3.103)		0.1778
UK 2	0.556 (0.204)	0.606 (0.220)	0.931 (0.429)	0.510 (0.179)	0.166 (0.059)	0.143 (1.588)		1.665 (0.481)	0.2803
Italy 1	1.336 (0.615)	0.136 (0.052)	2.131 (1.044)	0.393 (0.066)	0.197 (0.071)	7.674 (2.173)	3.747 (1.403)		0.4032
Italy 2	1.335 (0.615)	0.131 (0.051)	1.802 (0.943)	0.392 (0.065)	0.191 (0.072)	7.794 (2.824)		0.885 (1.701)	0.3722
Japan	1.552 (0.667)	0.006 (0.054)	1.555 (0.762)	0.139 (0.019)	0.424 (3.854)	2.473 (0.624)	2.618 (0.579)		0.3722

Table 7: Point estimates. Motor Vehicles . Asymptotic standard errors in parenthesis

	δ_1	δ_2	δ_3	η_1	η_2	η_3	η_4	η_5	CNR^2
Germ 1	0.523 (0.221)	0.289 (0.139)	3.616 (1.359)	0.849 (0.442)	0.417 (0.434)	0.541 (0.234)	0.427 (0.215)		0.4869
Germ 2	0.658 (0.231)	0.156 (0.058)	2.564 (1.042)	1.013 (0.354)	0.195 (0.847)	1.019 (0.156)		0.342 (0.166)	0.5212
Fran 1	0.832 (0.424)	0.156 (0.065)	0.873 (0.412)	0.601 (0.259)	0.241 (0.926)	0.223 (0.572)	0.756 (0.393)		0.3141
Fran 2	0.943 (0.449)	0.132 (0.065)	2.324 (0.997)	0.612 (0.239)	1.906 (2.141)	0.535 (0.280)		2.032 (0.486)	0.3897
UK 1	1.097 (0.537)	0.172 (0.072)	0.996 (0.369)	0.300 (0.085)	0.610 (0.884)	1.338 (0.592)	0.013 (0.65)		0.3916
UK 2	1.062 (0.501)	0.659 (0.230)	1.691 (0.599)	0.264 (0.091)	1.415 (0.402)	1.640 (0.483)		1.225 (0.504)	0.5158
Italy 1	1.533 (0.713)	0.082 (0.036)	2.808 (1.248)	0.036 (0.211)	0.917 (0.438)	0.107 (0.191)	0.036 (0.225)		0.6732
Italy 2	1.535 (0.707)	0.086 (0.036)	2.796 (1.248)	0.065 (0.191)	0.921 (0.430)	0.090 (0.214)		0.064 (0.024)	0.668
Japan	0.623 (0.309)	0.387 (0.101)	0.218 (0.103)	0.153 (0.066)	1.228 (0.250)	1.610 (1.829)	1.253 (2.237)		0.4192

Table 8: Point estimates. Electrical and electronics . Asymptotic standard errors in parenthesis

	δ_1	δ_2	δ_3	η_1	η_2	η_3	η_4	η_5	CNR^2
Germ 1	0.560 (0.239)	0.549 (0.169)	0.360 (0.153)	0.715 (0.361)	2.876 (0.625)	0.187 (0.425)	0.583 (0.685)		0.4878
Germ 2	0.563 (0.242)	0.498 (0.162)	0.615 (0.234)	0.685 (0.354)	2.863 (0.652)	0.031 (0.238)		0.831 (0.430)	0.4823
Fran 1	0.554 (0.222)	0.471 (0.175)	0.718 (0.314)	0.383 (0.911)	0.651 (0.657)	0.251 (0.124)	0.090 (0.257)		0.4067
Fran 2	0.621 (0.243)	0.732 (0.261)	1.083 (0.305)	0.291 (0.97)	0.521 (0.437)	0.147 (0.053)		0.942 (0.279)	0.5993
UK 1	0.168 (0.061)	1.386 (0.445)	0.570 (0.253)	0.341 (0.682)	0.526 (0.127)	1.328 (0.454)	2.167 (1.117)		0.4908
UK 2	0.195 (0.069)	1.441 (0.481)	0.993 (0.472)	2.617 (5.131)	0.518 (0.122)	0.720 (0.197)		1.701 (0.736)	0.4571
Italy 1	2.223 (0.707)	0.399 (0.162)	1.280 (0.453)	0.975 (0.225)	1.040 (0.419)	0.0035 (0.35)	0.378 (0.415)		0.6325
Italy 2	2.054 (0.664)	0.357 (0.158)	0.959 (0.347)	0.995 (0.227)	1.150 (0.461)	0.263 (0.313)		0.301 (0.627)	0.6285
Japan	0.267 (0.120)	0.665 (0.339)	0.561 (0.228)	2.201 (0.800)	1.007 (0.89)	0.321 (0.154)	0.120 (0.342)		0.4183

Table 9: Point estimates. Chemicals . Asymptotic standard errors in parenthesis

	δ_1	δ_2	δ_3	η_1	η_2	η_3	η_4	η_5	CNR^2
Germ 1	0.345 (0.141)	0.499 (0.193)	1.453 (0.610)	0.389 (1.389)	0.246 (0.302)	0.848 (0.303)	1.942 (0.477)		0.3952
Germ 2	0.336 (0.14)	0.463 (0.183)	0.464 (0.205)	0.358 (1.432)	0.279 (0.344)	1.133 (0.542)		0.008 (0.023)	0.202
Fran 1	0.892 (0.387)	0.161 (0.070)	1.583 (0.764)	0.604 (0.297)	0.0028 (0.056)	0.821 (0.912)	2.509 (3.136)		0.3946
Fran 2	0.899 (0.389)	0.166 (0.071)	1.296 (0.664)	0.615 (0.297)	0.010 (0.55)	0.972 (0.967)		4.730 (4.339)	0.4075
UK 1	0.661 (0.314)	0.355 (0.124)	0.425 (0.177)	0.076 (0.422)	0.23 (0.605)	0.431 (0.897)	0.625 (1.893)		0.328
UK 2	0.665 (0.313)	0.354 (0.123)	0.524 (0.207)	0.011 (0.366)	0.353 (0.619)	0.159 (0.691)		0.018 (0.024)	0.3302
Italy 1	0.468 (0.160)	0.527 (0.356)	0.521 (0.198)	0.031 (0.775)	1.079 (0.461)	0.235 (0.379)	0.185 (2.312)		0.3952
Italy 2	0.467 (0.160)	0.502 (0.205)	0.468 (0.176)	0.024 (0.801)	1.084 (0.473)	0.375 (0.364)		0.059 (0.026)	0.4183
Japan	0.318 (0.111)	1.431 (0.741)	0.083 (0.033)	0.451 (0.55)	0.875 (0.247)	0.686 (3.430)	0.641 (1.780)		0.4518

Table 10: Point estimates. Mechanical equipment. Asymptotic standard errors in parenthesis

	δ_1	δ_2	δ_3	η_1	η_2	η_3	η_4	η_5	CNR^2
Germ 1	0.330 (0.166)	0.435 (0.158)	0.989 (0.354)	0.057 (0.380)	1.184 (0.299)	0.33 (0.172)	1.671 (0.389)		0.443
Germ 2	0.325 (0.162)	0.456 (0.153)	0.833 (0.335)	0.023 (0.383)	1.180 (0.287)	0.197 (0.115)		1.181 (0.337)	0.438
Fran 1	0.363 (0.191)	0.783 (0.291)	1.420 (0.717)	0.235 (0.870)	0.878 (0.175)	0.328 (0.168)	1.493 (0.742)		0.465
Fran 2	0.292 (0.152)	0.845 (0.312)	0.862 (0.416)	0.395 (1.316)	0.831 (0.165)	0.695 (0.358)		0.454 (0.782)	0.450
UK 1	1.143 (0.549)	3.386 (1.604)	0.418 (0.177)	1.641 (1.263)	0.220 (0.108)	4.014 (2.069)	2.088 (1.033)		0.5149
UK 2	1.176 (0.560)	2.899 (1.348)	0.558 (0.212)	1.352 (1.207)	0.168 (0.067)	1.784 (0.929)		0.223 (0.155)	0.4749
Italy 1	0.609 (0.302)	1.642 (0.817)	0.435 (0.199)	0.701 (2.190)	0.025 (0.119)	0.043 (0.307)	1.0.18 (1.668)		0.4316
Italy 2	0.607 (0.301)	1.639 (0.819)	0.382 (0.133)	0.734 (2.224)	0.018 (0.12)	0.096 (0.346)		0.949 (1.090)	0.4317
Japan	1.039 (0.425)	0.195 (0.085)	0.415 (0.150)	0.341 (0.047)	3.380 (1.153)	0.533 (0.199)	1.866 (2.73)		0.364

Table 11: Point estimates. Aerospace. Asymptotic standard errors in parenthesis

δ_1 δ_2 δ_3 η_1 η_2 η_3 η_4 η_5 CNR^2

Germ 1	0.465 (0.186)	0.296 (0.131)	0.677 (0.356)	0.236 (0.095)	4.178 (2.51)	0.003 (0.112)	0.875 (0.324)		0.2894
Germ 2	0.411 (0.171)	0.253 (0.124)	0.731 (0.375)	0.210 (0.093)	3.605 (1.708)	0.044 (0.314)		0.939 (0.413)	0.2852
Fran 1	1.041 (0.505)	0.745 (0.292)	2.016 (0.861)	0.039 (0.150)	0.889 (1.59)	0.382 (0.168)	1.410 (0.498)		0.4458
Fran 2	1.021 (0.506)	0.768 (0.398)	1.707 (0.762)	0.027 (0.158)	0.892 (1.511)	0.444 (2.24)		0.209 (0.311)	0.4149
UK 1	0.356 (0.182)	0.483 (0.203)	1.045 (0.479)	0.037 (0.925)	0.059 (0.842)	0.312 (2.04)	0.316 (1.444)		0.2994
UK 2	0.355 (0.182)	0.475 (0.201)	1.123 (0.512)	0.001 (1.009)	0.085 (0.100)	0.264 (0.129)		0.141 (0.301)	0.2988
Italy 1	0.523 (0.273)	0.573 (0.205)	0.645 (0.286)	0.046 (0.766)	0.289 (0.283)	0.430 (0.796)	0.291 (0.970)		0.2591
Italy 2	0.590 (0.213)	0.852 (0.395)	0.579 (0.293)	0.584 (0.768)	0.375 (0.186)	0.320 (0.801)		6.036 (3.079)	0.5175
Japan	0.407 (0.190)	0.294 (0.135)	0.467 (0.303)	0.108 (0.156)	4.694 (2.006)	0.555 (0.973)	0.841 (4.426)		0.612

Appendix 1. The complete model for the estimation of eq. (5)

Table A.1 reports the model used for the estimation of eq. (5) in section 3. The version of eq. (5) used in this paper is different from the one used in Padoan (1996) which does not take into account regional effects of technology diffusion. As discussed in detail in Padoan (1996) the model was estimated simultaneously (FIML) where the parameters entering equations (1)-(4) and (7)-(8) were constrained to take on the values obtained in a preliminary stage of estimation. Eq. (11) was not used in estimation. Eqs. (8a) and (8b) were added to allow for the regional specification of high tech imports. The continuous time model is estimated by taking its approximate discrete analogue as described in Gandolfo (1981). Stock and flow variables are treated differently according to Gandolfo (1981). See also Appendix 2.1. TRANSF and RESIMUL programs, developed by Cliff Wymer have been used.

Table A.1 Model Equations

Export Share . Traditional Goods

$$D \log S_A = \alpha_2 (\log S_A^* - \log S_A) \quad (1)$$

$$\log S_A^* = \log \gamma_1 - \beta_1 \log P$$

Export Share. Scale Intensive Goods

$$D \log S_B = \alpha_3 (\log S_B^* - \log S_B) \quad (2)$$

$$\log S_B^* = \log \gamma_2 - \beta_2 \log P + \beta_3 \log T / T_w$$

Export Share. Specialized Suppliers

$$D \log S_C = \alpha_4 (\log S_C^* - \log S_C) \quad (3)$$

$$\log S_C^* = \log \gamma_3 - \beta_4 \log P + \beta_5 \log T / T_w$$

Export Share. Science Based Goods

$$D \log S_D = \alpha_5 (\log S_D^* - \log S_D) \quad (4)$$

$$\log S_D^* = \log \gamma_4 + \beta_6 \log T / T_w$$

Knowledge Accumulation

$$D \log T = \alpha_6 (\log T^* - \log T) + \sigma_1 \log T_{F1} + \sigma_2 \log T_{F2} + \sigma_3 \log S_{MH1} + \sigma_4 \log S_{MH2} \quad (5)$$

$$\log T^* = \log \gamma_5 + \sigma_5 \log F + \sigma_6 \log S_D$$

Aggregate Export Share

$$\begin{aligned} D \log S_X = & D \log S_A (S_A / S_X) (W_A / W) + \lambda_A (S_A / S_X) (W_A / W) + D \log S_B (S_B / S_X) (W_B / W) \\ & + \lambda_B (S_B / S_X) (W_B / W) + D \log S_C (S_C / S_X) (W_C / W) + \lambda_C (S_C / S_X) (W_C / W) \\ & + D \log S_D (S_D / S_X) (W_D / W) + \lambda_D (S_D / S_X) (W_D / W) - D \log W \quad (6) \end{aligned}$$

Import Share. Traditional Goods

$$D \log S_{ML} = \alpha_7 (\log S_{ML}^* - \log S_{ML}) \quad (7)$$

$$\log S_{ML}^* = \log \gamma_6 + \beta_{11} \log P$$

Import Share. High Tech Goods

$$D \log S_{MH} = \alpha_8 (\log S_{MH}^* - \log S_{MH}) \quad (8)$$

$$\log S_{MH}^* = \log \gamma_7 + \beta_{12} \log P - \beta_{13} \log T / T_w + \beta_{14} \log S_{XH}$$

Regional High Tech Import Share

$$S_{MH1} = \omega S_{MH} \quad (8a)$$

Extra Regional High Tech Import Share

$$S_{MH2} = (1 - \omega) S_{MH} \quad (8b)$$

Aggregate Import Share

$$D \log S_M = D \log S_{ML} (S_{ML} / S_M) + D \log S_{MH} (S_{MH} / S_M) \quad (9)$$

High Tech Export Share

$$S_{XH} = S_B (W_B / W_H) + S_C (W_C / W_H) + S_D (W_D / W_H) \quad (10)$$

Output

$$D \log Y = \alpha_1 (\log Y^* - \log Y) \quad (11)$$

$$\log Y^* = \log W + \log P_X + \log S_X - \log P_M - \log S_M$$

Variables

endogenous

- S_A Export share. Traditional goods
- S_B Export share. Scale intensive goods
- S_C Export share. Specialized suppliers
- S_D Export share. Science based goods
- S_X Aggregate export share
- T Stock of domestic knowledge
- Y Output
- S_{ML} Import share. Traditional goods
- S_{MH} Import share. High tech goods
- S_{MH1} Regional Import share. High tech goods
- S_{MH2} Extra Regional Import share. High tech goods
- S_M Aggregate import share
- S_{XH} Export share. High tech goods

exogenous

- P Relative price
- F Stock of R&D expenditure
- T_w Stock of foreign knowledge
- W Total foreign demand
- W_i Sectoral foreign demand ($i = A, B, C, D, H$)
- P_x Price of exports
- P_M Price of imports
- D d / dt

In the model we follow Pavitt's (1984) taxonomy to group manufacturing goods into four macrosectors. In this taxonomy¹⁵ manufacturing sectors are grouped according to the position each sector holds in the process of knowledge accumulation and diffusion, as well as on the role of knowledge and of other factors in determining performance. Thus this taxonomy, in addition to being quite suitable for the analysis of the interaction between trade and knowledge accumulation, has the advantage of providing an empirical classification of manufacturing sectors.

The four macrosectors are:

Traditional Goods. Innovative activity in this sector is limited yet necessary to allow absorption of innovations from other sectors. Process innovation leads to

¹⁵ Pavitt' taxonomy considers more than four sectors. Other sectors, in addition to the ones introduced in the model, are "food and agriculture" (resource intensive), energy intensive, information intensive (finance and retailing). For a recent reassessment and for the implications for development policies see Bell and Pavitt (1995).

productivity gains and “price competition” is crucial. Typical sectors include clothing and footwear¹⁶

Scale Intensive Goods Innovative activity in this sector is relevant especially in process and organizational innovations. Innovation diffusion from other sectors is obtained largely through acquisition of intermediate goods. Competitiveness derives from the exploitation of scale economies. Sectors include transport equipment, consumer electronics and household appliances.

Specialized Suppliers. Innovative activity relates to both process and product innovation and is often the result of consumer-producer interaction leading to special “customer relationships” with other sectors. Competitiveness derives from “quality”, mainly understood as the capacity to adapt to the users’ needs both in terms of performance and prompt delivery. Sectors include machine tools and scientific instruments.

Science Based. Innovation activity through substantial R&D investment is the main characteristic of these sectors whose competitiveness derives essentially from product innovation success. R&D performed in these industries typically leads to knowledge spillovers to other sectors which tend to be stronger the closer is the user producer relationship. In this respect science based firms acquire knowledge from other sectors as well as disseminating it. This relationship is usually strong with specialized suppliers firms. Sectors include aerospace industries, computers, telecommunications.

High Tech Imports are defined as total manufactured imports less imports of traditional goods.

Regional High Tech Imports are defined as the observed average share (ω) of regional imports in total imports of high tech goods

¹⁶ A complete classification of sectors used in this paper is available on request from the author.

Appendix 2. Data sources and definitions

A.2.1 Data used for the estimation of eq. (5) in paragraph 3

Data for exports and imports grouped according to Pavitt (1984) in nominal terms were partly provided by the Italian Institute for Foreign Trade (ICE) and partly elaborated by the author on the NIMEXE data base (Eurostat). Bilateral trade flows were elaborated by the author starting from IMF Direction of Trade Statistics data. The “world” aggregate includes: United States, Japan, Germany, France, Italy, United Kingdom. A detailed classification is available on request from the author. They have been transformed in constant dollar values at 1985 GDP price indices and 1985 PPP dollar exchange rates.

The stock of domestic knowledge T is the fractional patent count taken from the US Patent and Trademark Office cumulated on a benchmark initial value.

The stock of foreign knowledge T_w is defined as T but it includes the sum of patent counts for the countries entering the group defined above less the patent counts for the domestic economy. When the European stock of knowledge is used data for the US and Japan are excluded.

P is the real effective exchange rate (source: Bank of Italy)

F is the amount of private R&D expenditure transformed in constant dollar values at 1985 GDP price indices and 1985 PPP dollar exchange rates, cumulated on a benchmark initial value and depreciated at the rate of 15 percent a year. (source CNR 1992)

The sample period (annual observations) covers 1970-1991. All stocks were measured at the end of period while prices are period averages. All series measured at the end of period were adjusted in order to be consistent with flow data (Gandolfo 1981, equations (30) and (31) of chapter 3). This allows to consider variables which contain both stocks and flows in their definition. The approximate discrete analogue to the continuous model used for the estimation carried out in paragraph 3 was obtained as expounded in Gandolfo (1981), chapter 3 paragraph 3.2.2

A.2.2 Data used for the estimation of model (2.1)-(2.3)

The continuous time model (2.1)-(2.3) was also estimated (FIML) taking its approximate discrete analogue and data were treated as explained in Appendix 1. Following Fagerberg (1988), we introduce a measure of innovative activity including both inputs and outputs of innovative activity. We have computed a weighted average of two specialization indicators: one based on business enterprise R&D expenditures (BERD) and one based on patent counts. These two indicators are known as Revealed Technology Advantage (RTA) indicators, which correspond to the well known Balassa index used with trade data. This indicator, the index of “Industrial Technological Specialization” (ITS): is defined as follows

$$ITS = LQR\&S_{ij} \times a + LQPAT_{ij} \times b$$

where,

$$LQR\&D_{ij} = \frac{S_j \text{BERD}_{ij}}{S_i \text{BERD}_{ij} S_j \text{BERD}_{ij}} ; \quad LQPAT_{ij} = \frac{S_j \text{PAT}_{ij}}{S_i \text{PAT}_{ij} S_j \text{PAT}_{ij}}$$

$$a = \frac{(\text{stdLQPAT})}{(\text{stdLQPAT} + \text{stdLQR\&D})} \quad b = \frac{(\text{stdLQR\&D})}{(\text{stdLQPAT} + \text{stdLQR\&D})}$$

i : country; S_i refers to the six major countries aggregate;

j : sector; S_j refers to the manufacturing sector;

BERD : business enterprise Research and Development expenditures (BERD);

PAT : n° of patents granted in the US Patent and Trademark Office;

stdLQPAT, stdLQR&D: standard deviations of LQR&D and LQPAT, the two specialization indicators; we omit the index t, which refers to years from 1973 to 1990.

The use of standard deviations as weights is necessary to compare two variables showing different variability (note that the specialization indicators, LQR&D and LQPAT have the same dimension).

The ITS index varies between zero and ∞ . It will be greater than one if country i in sector j is technologically more specialized than other countries. It will be less than one if the country is despecialized. To measure commercial and productive specialization we use the traditional Balassa index, computed with export and production data, respectively:

$$IES_{ij} = \frac{\frac{\text{EXPORT}_{ij}}{S_j \text{EXPORT}_{ij}}}{\frac{S_i \text{EXPORT}_{ij}}{S_i S_j \text{EXPORT}_{ij}}} ; \quad IPS_{ij} = \frac{\frac{\text{PRODUCTION}_{ij}}{S_j \text{PRODUCTION}_{ij}}}{\frac{S_i \text{PRODUCTION}_{ij}}{S_i S_j \text{PRODUCTION}_{ij}}}$$

Data sources and classifications

Export, production and R&D data for 1973-'90 are taken from the OECD STAN/ANBERD data base (OECD, 1992), which reports variables in national currencies and current prices. These have been transformed them in dollar real values at 1985 prices, using the GDP price indices of the six countries and 1985 PPP US dollars .

Patent data are taken from the US Patent and Trademark Office data base and represent the number of patents granted by the USPTO according to the inventor countries. These are fractional counts: patents are originally classified by technological groups and then attributed to the industrial sectors which use these technologies. If one invention has more then one industrial sector of destination, only a fraction of this will be assigned to the sectors (e.g. if one patent has three sectors of use, each of these sectors will present one third of patent counts).

The sectors examined are the following: Textiles (ISIC 3200; SIC 22); Chemical Products excluding Drugs (ISIC 351, 352 except 3522; SIC 281, 284-287, 289); Mechanical Equipment including Computers (ISIC 3820; SIC 35); Electrical & Electronics (ISIC 3830; SIC 36, 3825); Motor Vehicles (ISIC 3843; SIC 371); Aerospace (ISIC 3845)

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