An Empirical Analysis of Technological Convergence Process and RJVs in Europe at the Firm Level

Patrizia Bussoli*
Universitat Pompeu Fabra Barcelona Spain

September 1999

Abstract

We use a new data set for European manufacturing firms to assess whether a short term technological convergence process has been taking place among manufacturing firms in seven European countries. The empirical analysis aims to study the effects of international co-operative R&D on short term productivity gains among European manufacturing firms and clarify the role of spillovers in the process of technological diffusion. We find substantial evidence of convergence across firms in Europe, that the overall convergence process is influenced by the presence of international R&D co-operation and that symmetric Research Joint Ventures (RJVs) increase productivity to a greater extent than RJVs between asymmetric firms. The convergence process is affected by the presence of RJVs, but in this analysis we do not detect that convergence is positively affected by country and sectoral trade and patents.

*I would like to thank Giorgio Barba Navaretti, Bruno Cassiman, Walter Garcia Fontes, Adriana Kugler, Luis Rivera Batiz, Diego Rodriguez, Alessandro Sembenelli, David Ulph for useful discussion, comments and suggestions. I also would like to thank Browyn Hall and Manuel Arellano for useful talks and insights.

1 Introduction[1]

Extensive literature has produced substantial evidence of income convergence (Barro and Sala-i-Martin (1995)) and productivity convergence between countries (Jaumotte (1998), Coe, Helpman and Hoffmaister (1997)). Studies looking at convergence at the level of the industry have raised doubts about convergence within the manufacturing sector. Bernard and Jones (1996) find little evidence of labour or multifactor productivity convergence in manufacturing and show that the results are independent of the method used to calculate multifactor productivity. A shortcoming of the current literature is that convergence is only examined at the 1-digit level. There is very little work on convergence at finer levels or at the level of the firm. However, convergence is a process that ultimately takes place at the firm level.

There is an extensive literature on the effect of R&D on Total Factor Productivity (TFP) growth at the firm level (Griliches (1973, 1985, 1991, 1992), Griliches and Mairesse (1985), Mairesse and Hall (1994)). This literature provides insights on the relationship between R&D and firm productivity, but has largely ignored the empirical role of co-operative R&D. There is plenty of room left for work focusing on understanding the role of co-operative R&D, which is a common practice both in the US and Europe, where Research Joint Ventures (RJVs) receive substantial national and international funding.

In this paper, we use a new data set for European manufacturing firms to assess whether a short term technological convergence process has been taking place among manufacturing firms in seven European countries.[2] The data set comprises a sample of 4,171 firms that provides detailed information about balance sheets, R&D agreements, and other variables. The data set allows us to measure technological change at the level of the firm by calculating firm TFP and examine technological convergence for the whole sample of firms and within the group of firms that form part of RJVs. The empirical analysis aims to study the effects of international co-operative R&D on short-term technological convergence among European manufacturing firms and clarify the role of spillovers in the process of technological diffusion.

---

[1]The "STEP to RJVs" project was co-ordinated by Yannis Caloghirou, National Technical University of Athens/Laboratory of Industrial and Energy Economics. Project participants are: NTUA/LIEE (Greece), SIRN (UK), FEEM (Italy), IDATE (France), Stockholm School of Economics (Sweden), Universidad III de Madrid (Spain), PREST (UK).

[2]Belgium, France, Germany, Italy, Netherlands, Portugal and the UK.

The empirical analysis proceeds in three steps. First, we assess the presence of countrywide and sectorial technological convergence among all firms in the sample, controlling for firms inside and outside RJVs. After short term convergence is established, we study more in depth the role of the characteristics of international RJVs in this process. We concentrate on the sub-sample of firms participating in RJVs to better understand the process of convergence and technological diffusion within the group of firms that join RJVs. Finally, we try to assess the extent to which the presence of RJVs in the different manufacturing sectors affects the technological gap between a given firm and the best performing firm in its sector. Thus the final step of the analysis is to construct the productivity gap (dispersion, distance term) which is comparable across sectors and to explain the distance measure from the best performing firm by characteristics of firms and of RJVs. If the knowledge or new technology developed in RJVs is transmitted to firms outside RJVs, then the productivity of firms (measured in levels) should be higher in those sectors with a larger presence of RJVs.

The literature on co-operative R&D and RJVs is rich in results at the theoretical level, modelling the effects of joining an RJV on R&D investment, product market effects and spillover effects. Due to the lack of detailed data at the firm and RJV level, there are very few empirical results. The only results available relate to RJVs formed in the US.[3] Our results provide a link between theoretical results and empirical evidence, supporting the notion of short term technological convergence among European firms.

2 Convergence, productivity and R&D co-operation at the micro level

The empirical convergence process has been extensively studied at the macro level (Barro and Sala-i-Martin (1995)), with contributions at the sectorial level aiming to understand the role of each sector in affecting the growth path (Bernard and Jones (1996a, b), Jones (1994, 1995), Bernard and Durlauf (1996)). Bernard and Jones (1996b), Cozzi (1998) and Haksar (1996) suggest that more effort should be devoted to analyse the microeconomics of the

[3] The few empirical contributions are on RJVs in the US (Vonortas (1997), Roller, Tombak and Siebert (1997)). Based on this new European database the empirical work includes Barba Navaretti, Bussoli, VonGraevitz and Ulph (1999), Marin and Siotis (1999) and Benfratello and Sembenelli (1999).

macro process. Recent results at the sectorial level emphasize the role of trade as a means of technological diffusion in affecting the process of technological convergence among OECD and non-OECD countries (Coe, Helpman and Hoffmaister (1997), Jaumotte (1998)). Using micro data allows us to capture other channels of the process of technology diffusion, such as the role of co-operative R&D and spillover effects across firms, which are key factors in the new growth literature. We follow the standard technological convergence approach, where the proxy used to measure technology is TFP.

The first question we answer is whether a short-term technological convergence process has been taking place and whether participation in RJVs favours this process across European firms. The analysis across countries and across different manufacturing sectors in Europe supports the hypothesis that RJVs favour technological convergence at the country level, although this effect is not statistically significant for the UK and Germany, and at the sectorial level for most of the 21 sectors examined, except total clothing, total ferrous products except machinery, total office machinery and computer, total radio, TV and telecommunication, total medical equipment, measuring instruments and watches, and total furniture and other manufacturing.

When we concentrate on the sample of firms participating into RJVs, we find out that there is convergence for all countries except for Germany and the UK. We also find that the convergence effect is stronger the higher the degree of symmetry among firms joining the same RJVs.[4]

For both the sectorial analysis of the sample comparing all firms and the sample of firms participating in RJVs we find that the higher the growth rate of capital the lower the technological growth rate. This result might suggest to us the presence of important adjustment cost factors in the adoption of new innovations that affect negatively the short term technological growth process.

The third question we address concerns whether the level of firm TFP is affected by R&D co-operation. We study the determinants of a dispersion term measuring the gap between a given firm and the sector's best-performing firm. The dispersion term has been constructed following the approach used by Ann Harrison (1993, 1994) in studying spillovers due to foreign direct investments. Our results show that R&D co-operation activity has a positive impact on the technological productivity distance. We find that larger firms have a greater distance from the best performing firm in their sector, so that

[4] Noting that the pool of firms joining RJVs are not all alike to start with.

they are less likely to achieve higher levels of technological productivity.

Summarising, we find substantial evidence of short term convergence across firms in Europe, that the overall convergence process is positively influenced by the presence of international R&D co-operation and that symmetric RJVs increase productivity to a greater extent than RJVs between asymmetric firms. RJVs are a tool of technology diffusion because they generate new knowledge among a group of firms, which are competitors in the product market. Co-operating in RJVs induces firms to share their knowledge among themselves and gives access to privileged information. The convergence process is affected by the presence of RJVs, but we do not find that sectorial and country trade and patents (in the country analysis) contribute to technological convergence. We still have to measure the impact of other industry-wide cross spillovers that do not depend on the presence of RJVs.

This paper is organised as follows. In the next section a theoretical model that supports our empirical test is presented; in the third section the data and the variables examined are described; in the following three sections we specify each step of the econometric analysis and present the results, which are discussed in the sixth section. A number of extensions are suggested in the conclusions.

3 R&D Co-operation and Growth: a theoretical framework

The empirical estimation is motivated by a simple endogenous growth model, based on Cozzi (1998), where the crucial factor is co-operative behaviour among firms in their R&D activity. In the one-factor case in which labour is the only input used in the economy, technological change is measured by labour productivity. In the multi-factor model, technological change is measured by total factor productivity. We can think of technology as a 'routine process' (Baumol 1993), where technology increases gradually over time.

3.1 Households

Agents maximize a utility function which is linear in the consumption index x(i,t) subject to a budget constraint that depends on labour income (labour is supplied inelastically) and non-human assets such as consumer loans granted and firm bonds and equities (which are assumed to be perfect substitutes).

The instantaneous demand of each good $i \in [0,1]$ is given by

$$x(i,t) = \frac{E(t)p(i,t)}{\int_0^1 p(j,t)^{\frac{-1}{(1-a)}} dj}, \qquad (1)$$

where $E(t)$ is nominal expenditure and $\frac{1}{(1-a)}$ is the constant elasticity of substitution.

3.2 Firms

Each good is produced by a monopolistically competitive firm, which faces a positive fixed cost representing overhead labour cost (n units of labour). Firms are engaged in Bertrand competition. Goods are produced under the same constant returns to scale technology using labour as the only primary factor. The technological level of the firm measures the average and marginal productivity of labour, denoted by $f(i,t)$. Product varieties do not change over time and real wages are equal to $af(i,t)$. Profits will be equal to total revenue minus variable labour cost and overhead cost. If firm i contributes to improve technology, it will hire workers $u(i,t)$ to carry out R&D. Thus the real value of the firm will be

$$V(i,t) = \int_t^\infty (C(s)(1-a) - u(i,s)f(s)a - nf(s)a)e^{\rho(s-t)}dt, \qquad (2)$$

where $C(s)$ is real consumption flow.

3.3 Technology

Technological progress $f(t)$ requires the joint R&D effort of a coalition of firms, according to the following law of motion,

$$\dot{f}_i(s) = \frac{a}{b}\int_{j\in A} Af(s)^b u(s)^b dj, \qquad (3)$$

for all $i \in A$, where A is the subset of co-operative firms whose indexes belong to [0,1] and A is assumed to have a positive Lebesgue measure. The parameter b, with $b < 1$, embodies the assumption of diminishing long term returns to technology as well as positive costs of accelerating the path of innovation, while the scalar productivity parameter a, with $a > 0$, captures the fraction of inventions that are successful in a risky context (the expression does not include uncertainty given the large number of firms). The integral summation implies that each firm's R&D effort contributes to overcoming diminishing returns of the other firms' R&D efforts, suggesting that R&D co-operation allows firms to exploit complementarities among their different production (Baumol 1993). The specification implies that technology increases in the number of workers employed by the firm in the lab ($u(s)$) and in the accumulated stock of knowledge ($f(s)$). An assumption about information sharing is the presence of equal sharing of information among firms joining the RJV but no information flows outside the group.

3.4 Co-operative Equilibrium

When firms join an economy-wide RJV they will maximize their common value function $V_C(f)$

$$V_C(f) = max_{u(.)} \int_t^{\infty} (C(s)(1-a) - u(s)f(s)a - nf(s)a)e^{\rho(s-t)} ds \tag{4}$$

subject to

$$\dot{f}(s) = \frac{a}{b} f(s)^b u(s)^b, \tag{3a}$$

which is the simplified expression of the law of motion under the hypothesis of symmetry. When firms maximize, given that they are rational agents, they know that[5] $C(s) = (L - u(s) - n)f(s)$ and consequently substitute it in $V_C(f)$.

Under co-operative behaviour, positive investment in R&D leads to positive economic growth. In the absence of co-operation, the investment in R&D employment will be zero ($u(s) = 0$) and consequently there will be no technological progress. The result also holds, under some changes of the monitoring system to prevent information leakages, when more RJVs are allowed. In this case, the monitoring system is more effective the smaller the coalition, due to free rider and moral hazard problems.

The maximization condition yields the optimal value of the firm under co-operation and the number of workers paid by each firm for carrying out R&D, which is

[5] L is total labour in the economy. The expression derives from labour market clearing conditions.

$$u^*(f) = \left[\frac{L(1-a)-n)a}{\rho}\right]^{1/(1-b)} f^{-1}. \quad (5)$$

When we substitute the previous expression into the technology equation we get

$$\dot{f} = \frac{a}{b}\left(\left(\frac{L(1-a)-n)a}{\rho}\right)^{1/(1-b)}\right)^{b} \quad (6)$$

If we divide by f and apply a log transformation, we end up with the following expression for the technological growth rate $ln\Delta f$:

$$ln\Delta f = lna - lnb - lnf + bln(L(1-a)-n)a) - \frac{1}{1-b}ln\rho \quad (7)$$

In this expression technological progress depends positively on the fraction a of successful innovation in a risky context and on the amount of labour available in the economy (size effect), and negatively on the initial level of technology (convergence hypothesis), on the labour overhead cost n and on intertemporal time preference ρ. The same equation may be read in terms of the conditions under which a firm can successfully grow, depending on its initial level of technological productivity, its product quality and size.

Equation (3a) is the basic equation we use for the empirical test. In this framework technology depends on the stock of accumulated technology and on investment in R&D labour. We will provide some changes due to data availability and further interpretations. Technology is measured by total factor productivity, estimated from a two factor production function.[6,7,8]

Dividing by f and transforming the variables into natural logarithm, we end up with the following expression:

$$ln\Delta f = lna - lnb + (b-1)lnf + blnu \quad (8)$$

which is equal to (7) when we substitute the optimal value of u.

[6] Details on the methodology of TFP construction are in Appendix 1.

[7] We refer to Chapter 12 by Aghion and Howitt (1998) for an extensive analysis of the measurement problems related to measures of technology.

[8] The model can be extended to an economy with two factors of production, without substantial changes in the results.

Technological progress is estimated with respect to the initial level of technology, the different channels by which knowledge can be accumulated (which are specified in detail in the following section 4), the R&D investment (although not at the RJV nor at the firm level for lack of data) and the size of the firm.[9] Moreover, results in the RJV literature suggest controlling for the influence of RJVs in terms of size and number of RJVs. Muller, Kamien and Zang (1994) present a model in which technology increases more under co-operative RJVs than under competitive RJVs. The more RJVs a firm participates in, the closer to cartelized RJVs and the greater the positive effect on technological progress. On the other side, theoretical results show that a high number of participants to RJVs reduces the firm's expected value, because it reduces expected post innovation profits (Martin (1994))[10] or increases the cost of monitoring the partners to prevent free-riding behaviour (Cozzi (1998)). This trade off between benefits and costs determine the optimal number of firms in an RJV.

4 Data and Variables

We use a data set[11] that includes information on RJVs between European firms in the period 1992-1996. The data are gathered from the Eureka and Cordis databases, which contain all the information on RJVs formed among European firms, under the umbrella of the European Commission (Cordis) and with other sources of funding, mainly national funds (Eureka). The RJVs comprise various industries but we focus on RJVs among manufacturing firms and between manufacturing firms and non-profit institutions such as research organisations and universities. We concentrate on manufacturing since it is one of the sectors more active in R&D co-operation and for which the

[9] We are not able to estimate an overhead cost, but we can control for the skilled cost of adopting new vintage of capital interacting the growth rate of capital and the skill variables.

[10] If the number of firms is large enough, expected value is greater if a firm takes a chance on having monopoly access to the new technology than if it is assured on having shared access to the new technology. In our analysis we cannot control for sharing of innovation among the partners of RJVs.

[11] The structure of the database is similar to the one constructed on RJVs in the US (Vonortas (1997)). It includes data on RJVs from Cordis and Eureka and firms' balance sheets information extracted from Amadeus database. R&D data at the firm level are from Worldscope database.

information to compute TFP at the firm level are more complete. Moreover, the previous sectorial studies underline the need to explore this sector more in detail, as a component of the aggregate convergence process.

4.1 TFP at the firm level

For each sector (at 3 digit Nace 91) we include the firms that took part in RJVs project: 434 of them have complete financial information over the period 1992-96. For 40 of them there are data on R&D investment for the whole period. We constructed a counterfactual of 3700 firms that did not join RJVs. The countries involved in the analysis are Belgium, France, Germany, Italy, Netherlands, Portugal and the UK. The counterfactual has been randomly extracted from Amadeus database, which is representative of European firms at the country and sectoral level. Table 1 shows the country and sector composition of the sample.

Analysis of TFP levels in the period 1992-96 (Table 1a) shows that TFP in both groups of firms inside and outside RJVs increased over the period. TFP means for the sample of firms participating into RJVs are slightly higher than those of firms outside RJVs, but the median for the two groups is similar. Also, firms joining RJVs are not the ones with the highest TFP in the sample. TFP variance in the group of firms joining RJVs is higher than in the other group: this suggests that RJV firms are more heterogeneous than non-RJV firms. Because the best performing firms are not RJVs firms we do not think there is a serious selectivity bias problem in that firms having higher TFP are to join RJVs.

The heterogeneity of firms belonging to RJVs may reflect the fact that one of the aims of co-operative R&D programmes is to encourage the participation of heterogeneous firms (large as well as small and medium enterprises), in particular in the case of projects financed by the European Commission, rather than encouraging the most productive firms.

The analysis of TFP growth over the period 1992-96 is summarised in Table 1b. The country analysis of TFP highlights a negative TFP growth over the period for the UK; Germany is the country with the highest TFP levels (in mean and in median). Graphs 1 and 2 relate TFP growth over the period 1992-96 and TFP at 1992 for the group of firms inside and outside RJVs. The graphs show a negative relationships between the two variables, suggesting the existence of a convergence process over this short time period in both groups of firms. When we relate TFP with measures of firm size (employment, operating revenue and value added) we find out that firms with a higher TFP are larger. Table 1c shows that firms joining RJVs are on average larger in terms of size, although the sub-sample does not include the largest firms in the overall sample. The group of firms outside RJVs is more homogeneous as shown by their lower variance. If we compare the size variable (just for employment) for the firms belonging to RJVs in Cordis and in Eureka, we find that the two groups of firms are rather homogenous (Table 1d).

5 Does technological convergence take place among European firms?

Standard growth literature emphasises the role of technological progress in generating higher growth: in our tests we try to model the different channels by which technological progress at the firm level takes place and is accumulated. Thus we test for some standard hypotheses and consider various control variables at the firm level.

According to the model sketched in section 2, we consider that technology is embodied in physical and human capital and in durable goods. In the proposed model we specify the following hypothesis. We want to test for a convergence hypothesis and a vintage hypothesis: the first one is formulated in order to measure whether the change in TFP is negatively correlated to the level of TFP at the initial period. The second one assesses whether the growth rate of TFP is positively correlated with the growth rate of capital. The vintage hypothesis states that new capital embodies innovation (Dollar and Wolff (1996)).

Typically the path of technology growth and the rate of innovation depend on two crucial factors (Mansfield (1961)): 1) the rate at which new technology and products are discovered depends on the level of R&D spending and on the sharing and diffusion of knowledge; 2) the rate at which these new products and technologies are introduced depends on the ease at which workers can acquire the skills required by technology development. Therefore we introduce a set of variables to control for R&D investment and R&D co-operation (RJVs), for technological spillover and for other channels of diffusion of technology, like trade, patents and for the skills available at the firm level (which is what in our model is defined as accumulated stock of human capital).

We first perform a pooled analysis, to see the general effect of RJVs at the firm level and then proceed with a sector and country specific analysis, as allowed by the kind of panel data set available. Because the data cover four years and many firms, our analysis is basically a cross section analysis. We take into account the econometric problems that arise when we pool data for the same firms over several years. We use a generalised least square estimator White consistent to correct for heteroskedasticity.

The pooled regression relates firm TFP growth between t_0 and t_n $\left(\Delta TFP_{i(t_n,t_0)}\right)$ to initial TFP (TFP_{it_0}), an interactive variable measuring initial TFP if the firm belongs to an RJV $(DTFP_{it_0})$, the growth rate of capital $\left(\Delta K_{i(t_n,t_0)}\right)$, an interactive variable measuring the growth rate of capital if the firm belongs to an RJV $(D\Delta K_{i(t_n,t_0)})$, and a number of control variables:

$$\begin{aligned}\Delta TFP_{i(t_n,t_0)} &= a_0 + a_1 TFP_{it_0} + a_2 DTFP_{it_0} + a_3 DK_{i(t_n,t_0)} \\ &\quad + a_4 D\Delta K_{i(t_n,t_0)} + a_5 CONTROL_{i(t_n,t_0)} + \varepsilon_{i(t_n,t_0)} \qquad (9)\end{aligned}$$

D represents a dummy variable equal to 1 if the firm participates in a RJV and 0 otherwise. $CONTROL_{i(t_n,t_0)}$ is a 1xz vector that includes variables[12] used to control for the process of technological accumulation and diffusion and size effects, which are assumed to be exogenous. $\varepsilon_{i(t_n,t_0)}$ are non observable error terms, assumed to be normally distributed and heteroskedastic. a_0 is the constant term, assumed to be equal across all individuals. When we test for group effects then the constant term will be equal along the country or the sectorial dimension.

The convergence hypothesis asserts that the rate of technological convergence is negatively related to the initial level of TFP (a_1 should be negative). The vintage hypothesis is tested by examining the growth of capital net of depreciation. If the vintage hypothesis holds, we would expect new capital to incorporate innovation and the coefficient a_3 to be positive.

The coefficient of the interactive variable $DTFP_{it_0}$ is used to test whether convergence rates differ for firms which take part in RJVs and firms that do not participate in RJVs. There will be a difference when the sum of a_1 and a_2 is positive, that is RJVs favour convergence. A positive sign of the sum

[12] Appendix 3 presents the various variables used and the details of the construction.

of the coefficients a_3 and a_4 indicates that there is not a different behaviour of the firms belonging to RJVs regarding the vintage hypothesis, that is the innovation embodied in new capital is stronger for firms participating in RJVs.

5.1 Sectorial and country effects

The pooled analysis specification assumes that the coefficients are the same for all firms in the sample (i.e., all the firms have the same alfa). Because one of the aims of the analysis is to consider whether there is convergence across different sectors and convergence across countries, we also examine sectorial and country effects. A companion paper (Barba Navaretti and Bussoli, 1999) performs the analysis across regions in the extended version with regional data, considering two main regional areas formed respectively by the most and less advanced countries.

The sector specific analysis allows studying the specific coefficients at the sectorial level (pooling across countries). The general sector-specific regression is:

$$\begin{aligned}\Delta TFP_{ij(t_n,t_0)} &= a_0 + a_{1j}TFP_{ijt_0} + a_2 DTFP_{ijt_0} + a_{3j}\Delta K_{ij(t_n,t_0)} + \\ &\quad a_4 D\Delta K_{ij(t_n,t_0)} + a_5 CONTROL_{ij(t_n,t_0)} + \varepsilon_{ij(t_n,t_0)} \qquad (10),\end{aligned}$$

where the subscript j indicates sector j (considered at a 2-digit specification in order to have enough degrees of freedom to construct the estimators).

The country specific analysis allows studying the coefficients at the country level (pooling across sectors):

$$\begin{aligned}\Delta TFP_{iv(t_n,t_0)} &= a_0 + a_{1v}TFP_{ivt_0} + a_2 DTFP_{ivt_0} + a_{3j}\Delta K_{iv(t_n,t_0)} \\ &\quad + a_4 D\Delta K_{iv(t_n,t_0)} + a_5 CONTROL_{iv(t_n,t_0)} + \varepsilon_{iv(t_n,t_0)} (11),\end{aligned}$$

where subscript v indicates country v. The same hypotheses for the error term as in equation (9) apply here.

5.2 Convergence and Vintage Hypothesis: General and Specific Results

Tables 2a and 2b show the results of the econometric analysis with pooled data. The convergence and the vintage hypotheses[13] find supports in the pooled regression results. The coefficient of initial TFP is negative and significant, with a coefficient of -0.006 in the country analysis and -0.004 in the sectorial analysis (that may be interpretred as speed of convergence); the coefficient of the growth rate of capital is positive and significant. An additional unit of capital growth increases TFP growth of 0.11, on average.

The low R^2 is typical of pooled regressions conducted at the level of the firm or individual agent, as individual variation dominates the variation explained by explanatory variables. The sector-specific and country-specific analyses show better R^2 performance than the pooled regressions. This indicates that the specific effects are relevant in accounting for the convergence process.

Given the existence of an overall convergence process, the fixed effect analysis (Tables 2c and 2d) reveals the presence of group effects at the country and at the sectorial level.

The country (Table 3) and sectorial (Table 4) analyses support both the convergence and the vintage hypotheses for all the countries, except for Germany and the UK, countries for which the coefficient of TFP is positive, not significant and close to zero. The speed of convergence is higher for Portugal and lower for Italy than in the other countries. The sectorial analysis is consistent with the convergence hypothesis in most sectors (except for sector "total clothing", "total ferrous products except machinery", "total machinery and computer", "total radio, TV and telecommunication", "total medical equipment, measuring instruments and watches", and "total furniture and other manufacturing"). The results suggest the convergence process is relatively uniform across those sectors exhibiting convergence, with an average speed of convergence of -0.015. However, the role of innovation embodied in capital is different across sectors. The only sector with a positive and significant coefficient is "total tobacco" (equal to 0.383), with the others having a negative coefficient: the vintage hypothesis is not supported by the results. The findings may reflect the presence of adjustment costs of adopting new

[13] Although correlation among variables is not detected, in interpreting the results we are acknowledged of potential problems with the vintage hypothesis due to simultaneity or omitted variables.

capital and the new technology it embodies across sectors.

The sum of the coefficients of the interactive variable $DTFP_{ivt_0}$ and the TFP variable have a negative sign in the pooled (sector), sector-specific and country-specific analysis, except for Germany, the UK and Italy. This result is confirmed in the sub sample of firms participating in RJVs (see section 5 below), although with some differences regarding the sectors and Germany, which shows convergence.

This suggests that there is an overall short term convergence process that takes place across the whole sample, although with differences in the sub sample of firms joining RJVs. Firms participating in RJVs are more involved in research than the whole group of firms, and other characteristics such as firms' asymmetries may help to explain the result. This supports the need for a more accurate study of firms participating in RJVs.

The negative value for the coefficient of the interactive variable $D\Delta K_{i(t_n,t_0)}$ in Table 4, which gives a negative value when summed to the coefficient of the growth of capital variable, indicates a rejection of the vintage hypothesis for those firms that form part of RJVs, except for France, Portugal and some sectors. Table 4 restricts the effect of the growth rate of capital to be the same across all firms that belong to RJVs, but we also obtain negative coefficients in the unrestricted regressions (not reported). The results suggest the rejection of the vintage hypothesis in the sub-sample of firms joining RJVs. This result is confirmed when we consider the sub sample of firms joining RJVs.

5.3 RJVs, Trade and Other Channels of Technological Diffusion

Recent work has examined the presence of technological spillovers from trade (Coe, Helpman and Hoffmaister (1995)), and from foreign direct investment (Neven and Siotis (1996), Blomström and Kokko (1997)). Our aim is to control for the different channels by which transfer of technology can affect TFP growth at the firm level. The control variables in the regressions identify different channels through which the technological diffusion process may take place. These include effects due to R&D co-operation, investments in R&D, employment in research, sectorial openness, protection for invention in each sector, and others.

Are there effects on short term convergence across firms due to the presence of RJVs? We attempt to measure this effect using two variables related to R&D co-operation: one control variable measures the number of RJVs in which firms are involved ("RJVtot") and the other measures the size of RJVs ("spimean"). The first term controls for firm involvement in R&D projects: the higher the number of RJVs for each firm, the greater the possibility to reduce R&D costs and avoid duplication costs. The idea is related to the theoretical result by Muller, Kamien and Zang (1994), where cartelized RJVs improve technology more than competitive RJVs. The higher the number of RJVs to which a firm participates, the less the competitiveness of RJVs (or the closer to a cartelized RJV). The second term controls for the partnership of each firm to assess whether the ability to co-ordinate research with more partners is beneficial to information sharing. Theoretical results emphasise that a high number of participants to RJVs reduces the firm's expected value, because it reduces expected post innovation profit (Martin (1994))[14] or increases the cost of monitoring the partners to prevent free-riding behaviour (Cozzi (1998)).

The pooled, sector-specific and country-specific regressions yield positive coefficients for the number of RJVs. The higher the number of RJVs, the stronger the effect on short term productivity growth.[15] An increase in the participation in an additional RJV increases TFP growth by 44 in the country analysis and by 26 in the sectoral analysis. This may be explained in terms of achieving R&D results at lower costs (thank to the presence of subsidies) or of sharing R&D costs (thank to the participation of other firms) and of avoiding fruitless efforts. It also suggests the idea that participating in more projects allows the firm to benefit of 'instantaneous' increasing returns to investment in R&D. If this is true and lowers the cost of new innovations, it may account for a part of industry wide spillovers. The participation to more RJVs strengthen the non-rivalry use of technology. We also estimate a regression that accounts for a non linear specification of the spillovers variable. The pattern of spillover due to the number of RJVs joined by the firms seems to follow a non-linear diffusion process, tested by the introduction

[14]If the number of firms is large enough, expected value is greater if a firm takes a chance on having monopoly access to the new technology than if it is assured on having shared access to the new technology. In our analysis we cannot control for sharing of innovation among RJV partners.

[15]The result is very robust across all the estimation: this supports the need for further investigation of the spillover effects due to RJVs. Refer to the discussion and conclusion sections for future work on this topic.

of a quadratic form of the RJVs spillover variables (which control for RJV number and size).

The results on the size of the RJV variable (which controls for the number of participants) suggest that the larger the number of participants the smaller the effect of co-operation on the technological diffusion process. An increase of an additional participant to the same RJV reduces TFP growth of 0.045 in the country analysis and of 0.026 in the sectoral analysis. This effect is possibly due to the fear of loss or diffusion of strategic firm information or to the existence of free-riding behaviour.

What is the relevance of the availability of skills at the firm level for the technological diffusion process? The availability of high quality labour is a key aspect for successful implementation of technology. The variable "skill" measures the level of skills for the firm. The pooled, sectorial, and country regressions yield a positive coefficient for the "skill" variable, even though we do not always obtain statistical significance. When we interact the skill variable with the capital growth rate ("Skag"), we find a negative coefficient (the variable is not always significant). The result may be explained using the following idea: higher capital growth requires a greater amount of skills to be implemented. The absorption of these skills retards convergence.

We also consider a vintage hypothesis in terms of R&D employment in manufacturing at the country level. We examine the effect of the growth rate of manufacturing R&D employment for each country ("rag") on firm TFP growth. The idea is that the growth rate of R&D employment might have a positive effect in technological change. This growth rate might reflect innovation in human capital brought by a new generation and the acquisition of new ideas such as those transferred by new employees coming from rival firms. We found that the coefficient of this variable is negative. In other words, we could not detect in our sample that the skills required to foster technological growth are embodied in the new generation of workers or in new aggregate employment in research. This might mean that technological innovation is dependent on skills acquired inside firms or sectors rather on country skills.

The results on the "skill" and R&D labor growth variables might appear to be opposed but they measure different effects. The positive effect of the skill variable indicates that successful technological progress depends on the availability of skilled labour at the firm level. The growth rate variable is at the aggregate level and it does not embody information on the skill quality of the labour employed in R&D at the firm level. The skilled-labour puzzle, in the sense that growth in aggregate R&D employment is not related to productivity improvements, is a standard puzzle in the growth literature.

When we control for sectorial (3-digit) and country openness ("openness") as a channel for technology diffusion, we find a negative coefficient, equal to -0.04. We were not able to detect spillover effects from trade on technology growth at the firm level. These results are puzzling in that they are opposed to the aggregate results obtained by Coe, Helpman and Hoffmaister (1997) and Jaumotte (1998). The different results might be due to different construction of variables or to the fact that the cited studies consider OECD and non-OECD countries, while we focus just on a sub sample of OECD countries that are active mutual trading partners and have similar levels of technology.

Patents both serve as a measure of innovation and its diffusion, and represent an effective means of protecting innovation. We use the growth rate of patents applications at the sector and country level ("pag"). We find that in the country analysis an increase of an additional patent application reduces TFP growth of 0.09 on average, while in the sectoral analysis it increases TFP growth of 0.14. On one side the negative coefficient for this variable in the country analysis supports the notion that patents are a means of protecting innovation and prevent diffusion. On the other side, in the sectorial analysis the positive sign suggests that patents are used as an instrument of diffusion of technology within the same sector across countries. This result may suggest that the diffusion of information among different sectors (in the same country) is not strong. Unfortunately, patents at the firm level are not currently available to us, to go more in depth in the analysis.

Finally, we control for size, as suggested by the theory of the firm literature: it affects the growth process of the firm. We find that size, as measured by the natural logarithm of employment, affects negatively the short term technological productivity growth. The positive sign of the squared size variable (not reported) implies the existence of a $\frown$-shaped relationship between technological growth rate and size of the firm, in other words, medium enterprises have the highest growth rate, which is declining the greater firms are. However, if we interact size with the skill indicator we find a positive significant result. This result may mean that the increase in size is fruitful for the firm technological growth if it is joint with an increase with the skills embodied in the employees.

6 Convergence and spillovers between firms that participate in RJVs

This section focuses on the sample of firms taking part in RJVs. We examine the short-term convergence process for the sub sample of firms that belong to RJVs, spillovers between firms that belong to RJVs, and the role of RJV structure in promoting convergence. The countries included in the sub-sample are Belgium, France, Germany, Italy, The Netherlands and the UK. Sectors "total tobacco", "total wood products" and "total furniture and other manufacturing industries" are excluded for lack of information.

In order to examine the role of various RJVs characteristics, we introduce control variables measuring characteristics like kind of partner (firm or public institution), type of programme (Eureka or Cordis or both), and the asymmetry between the partners in an RJV.

Do RJVs allow for a more efficient sharing of resources and higher short term productivity gains among asymmetric or among symmetric partners? Theoretical results on the effects of RJVs are mainly carried out considering symmetric firms. When ex -ante firms heterogeneity is allowed, firms differences, after the R&D co-operation game, may die or amplify depending on market characteristics (Roller, Sinclair and Desagné (1996)) or on R&D cost functions (Van Long and Soubeyran (1996), Amir and Wooders (1997)). There exists a trade off between the allocative production gains from R&D co-operation and the inefficiency of carrying out R&D activities at different marginal costs. This trade off diminishes as firms become more symmetric. Our theoretical background is based on a hypothesis of symmetry among firms joining the same RJV. However, in the empirical analysis we can control for the existence of asymmetries among partners.

Asymmetries[16] are defined in terms of efficiency as measured by profit margins or return on total assets. We define different threshold levels of asymmetries for each multi-partner RJV (see appendix 3). An RJV asymmetry scale ranging from 0 to 7 is established, where 0 indicates a high degree of symmetry and 7 indicates a high degree of asymmetry. We use this scale to measure the degree of asymmetry of each RJV. This allows us to quanti-

[16]The analysis of asymmetry among firms participating in RJVs show they are not equally symmetric. The group of firms joining RJVs is more heterogeneous than the group outside RJVs as shown in the data analysis of section two and as it appears from the analysis in the paper by Barba et al (1999).

tatively distinguish between those firms that take part in asymmetric RJVs (i.e., composed by firms with different levels of initial efficiency) and those that take part in symmetric RJVs (i.e., composed by firms with equal levels of initial efficiency).

We run regressions based on a variant of equation (9) including the degree of asymmetry and other control variables as explanatory variables. For any threshold degree of asymmetry (ranging from 0 to 7), the dummy variable D is equal to 1 if the RJV in which firm i participates has an asymmetry level greater than the threshold level chosen, and D is equal to zero otherwise. The dummy variable is interacted with the initial level of TFP and the growth rate of capital. This allows us to assess whether the degree of asymmetry affects the rate of technological convergence, and whether the degree of asymmetry influences the effect of the growth rate of capital on the rate of convergence. The methodological considerations related to equation (1) continue to apply here.

Tables 5a and 5b containing the pooled regressions show that the convergence hypothesis is confirmed for the sub-group of firms that belong to RJVs, with a speed of convergence of -0.005 in the country analysis and of -0.01 in the sectoral analysis. The fixed effect analysis (Tables 5c and 5d) in this sub-sample underlines the existence of group effects at the country and sectorial level. The convergence hypothesis fails for Italy and the UK (see country-specific regression in Table 6) and for sectors "total leather and leather goods", "total ferrous products except machinery" (see sector specific regressions in Table 7). The country result on the UK may be due to its negative growth rate of TFP. The convergence hypothesis fails for Germany in the overall sample, but is satisfied in the RJV group: the effect in the total sample should be driven by the firms outside RJVs, which could be related to the post unification process that took place in Germany after 1990.

The previous section result on the possible existence of adjustment costs in the adoption of new capital that may inhibit technological growth is confirmed in this group of firms as well (Tables 5a and 5b). In particular an increase of an additional unit of capital decreases TFP growth of 0.2 in the country analysis and of 0.03 in the sectorial analysis. The country and the sector specific analysis (Tables 6 and 7 respectively) show this is true in particular for France and The Netherlands and for sectors "total textile", "total chemical" (both not significant), "total leather and leather goods", "total publishing and printing", "total rubber and plastics" and "total ferrous production". We notice that the coefficient of the interactive variable ("Skag") used to control for skill needed related to capital growth in this case is barely significant.

The channels of technological diffusion that characterise the group of firms involved in co-operative R&D are the availability of skilled labour, patenting and the spread of knowledge within the RJV group and the possibility to share R&D costs due to the participation in a high number of RJVs. All these variables, except patenting, have a positive coefficient in the convergence regressions. Notice that the coefficient of aggregate patenting had a negative sign in the whole sample regressions in the country analysis but it had a positive sign in the sectorial analysis. For the sub sample of firms belonging to RJVs the sign is always negative, with a coefficient of 0.5 in both country and sectorial analysis. This let us wonder whether patenting is used as a means of sharing knowledge and diffusing innovation among the firms that join RJVs. Possibly, this depends on sharing of property rights among the partners in the RJV and many patents might have not been obtained jointly, because of research duties distribution among partners. The coefficient of the growth in size is found to be negative and the $\frown$-shaped relationship between size and the TFP growth is still supported, while the interactive variable 'size and skill' is not significant (not reported).

Is this diffusion process affected by the characteristics of the RJV? Co-operating with private firms or public institutions is not found to be a significant variable. We utilise a dummy variable that assumed values of 0, 1, and 2 according to whether the firm joined the program sponsored by Eureka, Cordis or joined both programs. Participation in Cordis (the programme financed by the European Commission) positively affects total factor productivity. This suggests the idea that the presence of subsidies (as in Cordis) favours R&D co-operation which finally benefits short term productivity growth. The kind of research carried out within Cordis is pre-competitive research. The result is supported by the theoretical founding that RJVs at the pre-competitive level are more effective, because spillovers are higher and also outsiders may benefit from such agreements (Geroski (1992)).

We reject the hypothesis that asymmetry (measured in terms of efficiency) between firms participating in RJVs is associated with higher productivity growth. In the country analysis, the results suggest that the more symmetric RJVs partners are, the stronger the convergence and the smaller the role of new capital vintage across countries. This results holds for all levels of asymmetry greater than 2.

In the sector specific analysis (Tables 6 and 7), the only significant coefficient is for an asymmetry level equal to 1. This suggests that convergence is stronger when similar firms co-operate together in the same RJV. In case of symmetry defined with respect to the return on total assets, the interactive variable is always significant. This result does not allow us to determine the effect of asymmetry with respect to the convergence hypothesis at the sectorial level along this dimension. The more symmetric the firms, the more efficient the joint R&D investment, since it increases the monopoly power in R&D for the symmetric partners.

With respect to the vintage hypothesis, in the sector specific analysis, the sign of the interactive variable is positive as the sum with the coefficient of the growth rate of capital. This suggests that the more asymmetric the firms belonging to an RJV are, the more effective the new vintages of capital are. The result holds for threshold levels of asymmetry larger than 2.

7 Do RJVs increase industry total factor productivity?

We refine the analysis a bit further by studying the role of RJVs in affecting the level of total factor productivity in the industry to which they belong. If the knowledge or the new technology developed in RJVs is transmitted to those firms that do not join RJVs, we would expect that the productivity of firms (measured in levels) is higher in those sectors with a larger presence of RJVs. RJVs are not necessarily harmful to non participating firms, because of the externalities involved (disclosure of new knowledge, considered as a non rival good (Geroski (1992)). This approach should help to detect this aspect concerning intra-industry spillovers.

We perform a sectorial analysis where we construct a dispersion term that is comparable across sectors. We define a deviation term consisting of the difference between firm TFP and the TFP of the most efficient firm in each sector. For a sector j composed of N firms, the TFP of the firms in the sector are denoted $a_{1j}, ...a_{Nj}$. Relative efficiency for firm i in sector j is given by z_{ij} where

$$z_{ij} = a_{ij} - a_j$$
$$a_j = \max_i (a_{ij})$$
$$i = 1, ..., N.$$

A large negative value for z_{ij} means that firm i is very inefficient with respect to the most efficient firm in sector j.

Normalising z_{ij} so that the productivity gap can be compared across different sectors, let us define u_{ij} as the normalised deviation of firm level productivity from the best performance level for the sector:

$u_{ij} = \frac{a_{ij}-a_j}{a_j}$

$a_j = \max_i (a_{ij})$

$i = 1, ..., N$ for each sector j.

The dispersion of productivity across firms in sector j at time t can be related to firms and RJVs characteristics, to see the role of each variable in explaining firms technological efficiencies:

$$u_{ij} = f(RJV characteristics,\ RJV sector_j,\ Size_{ij},\ Pat_{ij}), \qquad (12)$$

where $RJV sector_j$ is the share of firms participating in RJVs in sector j, $Size_{ij}$ is a measure of the size of the firm expressed in terms of employment or sales relative to the employment or sales of the best performing firm in the sector, Pat_{ij} is the number of patent applications in the sector of the country to which the firm i belongs. We introduce an interactive variable for those variables at the firm level, where a dummy is equal to 1 for firms participating in RJVs and 0 otherwise.

The analysis utilizes a sectorial cross section panel pooled across countries defined at time t =1996. We control for sector specific effects to estimate the strength of the spillover effects across countries in the same sectors. To indicate sector specific coefficients we sub index them by j.

7.1 Results

Tables 8 and 9 report the results of the pooled and sectorial analyses. The examination of the productivity dispersion term across firms in each sector shows the role of the chosen variables. All variables are highly significant.

The coefficient of the RJV sector variable ("RJV-sect", a measure of the impact of RJVs on the distance from the best performing firms) is positive and significant: the higher the number of RJVs in each sector, the lower the distance from the best performing firm. The presence of RJVs affects positively the performance of firms in each sector, suggesting the existence of spillovers to firms outside RJVs, in the same sector in which the RJV takes place. The results show the number of RJVs in which a firm participates significantly affects the productivity distance from the best performing firm in the sector. The higher the number of RJVs in which a firm participates, the smaller the deviation from the highest productivity firm in the sector. The size of RJVs as measured by the number of partners is not significant.

Firm size is measured by employment (the other measure of size, sales, is found not to be significant). We find that larger firms are less likely to achieve higher levels of technological productivity, although there are group effects as underlined by the fixed effect analysis (Table 8a). This is confirmed in the sector specific results, which show that this effect takes place in all sectors but "total tobacco" (although the estimated coefficient is close to 0). Thus, each sector appears to have a different level of labour intensity in technology. The coefficient of the interactive variable for size shows that the size effect for the firms participating in RJVs is almost null.

The greater the degree of openness and of patent applications at the sectorial level, the smaller the distance of firms' productivity from the best performing firm in the sector. Thus, even though the trade and patent variables in the previous results do not seem to increase the growth rate of technological productivity, they exert a level effect in that they reduce the technological distance between firms in the same sector. The result on patents is consistent with the previous result found in the sectorial analysis in section 5. The sector specific analysis shows this is true for almost all the sectors.

8 Discussion

The analysis shows the presence of an overall process of short-term technological convergence among sectors and countries in Europe. The microeconomic dimension of the short-term productivity pattern appears relevant. The negative sign of the vintage hypothesis is consistent with findings by Dollar and Wolff (1996) on manufacturing in European Union.

We do not detect effects of technological diffusion from trade at the firm level among European countries and sectors. This may be explained by the fact that they are similar economies (all OECD countries) characterised by free markets, so that the arguments used by Coe, Helpman and Hoffmaister (1997) and Jaumotte (1998) do not apply here.

The positive convergence effect of the skill variable suggests that one aspect to explore in the growth literature is the role of skill acquisition. Some studies in the literature could be devoted on the supply side of skilled labour.

Firm size effects seem to play a negative effect on the process of technological convergence and have a $\frown$-shaped relationship with the technological growth rate. This result should be related to other empirical findings, in particular those that study firms size and firm participation to R&D agreements (Colombo, (1995)).

The results on the inverse relationship between size and the distance from the best performance firm in the sector underline that role played the size of employment in affecting the technological productivity. Is there a negative role played by labour with respect to technological productivity?

Finally, the presence of international technological co-operation seems to affect the process of diffusion and creation of knowledge, giving some support to the theoretical work in which R&D co-operation is modelled in a convergence framework (Cozzi (1998)). It is in line with one of the first empirical work on spillover and R&D cooperation (Cassiman and Veugelers, (1998)). The positive role played by symmetries, although it deserves more attention in future empirical work, lets us think that similar firms may be more successfully involved in R&D co-operation. This result is in line with theoretical predictions. R&D co-operation is more effective for firms with similar R&D cost functions, and the reduction in R&D costs and sharing of information effects on the short-term technological productivity may be stronger.

The overall result is that RJVs do favour a short-term technological convergence process and generates positive spillover effects. These effects do not follow a linear pattern: room is left for extensions aiming to understand better how spillovers work. The theoretical literature on RJVs and spillovers only considers different degrees of linear spillover effects.

9 Conclusion

This analysis provides insights about the process of overall geographic and sectorial short-term technological convergence within European Union and its relationship with co-operative R&D.

We focus the attention on the RJVs formed in the European Union in the 92-96 period, given the growing importance of this phenomenon in Europe and the deep involvement of the European Commission in providing sources to finance them. The lack of results in the empirical literature on RJVs in general in this sense and in particular in Europe has been mainly due to the paucity of data available till now.

The empirical analysis we present supports the hypothesis of short-term convergence and in particular the positive role played by international co-operation in R&D. It emphasises the country and the sectorial dimension in the overall process. We also find that Cordis program influences positively the short term convergence. Because some of the results may be dependent on the specification adopted, some extensions of the study are required.

First, an analysis considering each sector individually could be developed, if data availability allows for it. Second, some variable specification should be studied at the firm level like R&D investment and patents applications, as soon as these data become available.

The analysis of spillover effects should be able to control for industry wide spillovers using a neighbouring effect approach (Manski (1993)). In this way we could take into account the effects of other forms of R&D co-operation not included in the analysis and for which data are not available. Moreover it could be useful to construct a measure of technological closeness given by the number of patents in common fields (Jaffe 1986), once firm patent data are available. It should control for skilled labour turnover among firms: transfer of knowledge may also be due to R&D employment, its training and its turnover among firms. We thus require additional information at the firm level on the acquisition of skills, training of labour, turnover of skilled labour among firms.

The analysis of spillover due to RJVs should control for investment in R&D conducted through RJVs relative to total investment in R&D at the firm level, to better understand the role of RJVs in the knowledge acquisition process of firms.

Moreover, a further extension of the study of spillover would be in computing TFP at the sectorial level and studying TFP at the firm level with respect to TFP at the sectorial level and see whether they are covariant. Finally, an extension of the dispersion analysis could be in testing the difference between final and initial dispersion over the time period considered across the same set of RJV and firm characteristics.

10 Appendix 1: Methodology of construction of TFP

In the construction of TFP, we used a two-factor production function, with factors being the number of workers and capital, added value being the output.

The steps of construction are the following:

1. We deflated added value with the corresponding three digit production deflators, base year 1992;

2. We constructed Investments at time t (I_t) as the difference between Capital at time t (C_t) and Capital at time t-1 (C_{t-1}); then capital in "real" term (i.e. compared to the 1992 stock of capital) was computed according to the following formulas:

If $I_t > 0$, $C_t = C_{t-1}(1 - 0,0625) + I_t(\frac{definv_{92}}{definv_t})$

If $I_t < 0$, $C_t = C_{t-1}(1 - 0,0625)$

The use of a mortgage rate of 6,25% corresponds to an economic life of sixteen years. $definv_{92}$ and definvt indicate the deflator of investment goods, specific to each country, corresponding to year 1992 and t respectively. In this way, we used 1992 as the benchmark year.

3. To compute the shares of labour we have estimated a two ways fixed effects model for each of the 21 two digit sector; as we imposed constant return to scale the share of capital was equal to: 1-share of labour. Hence, the estimated equation has been:

$$log(\frac{Y_{it}}{C_{it}}) = a_i + \gamma_t + \beta log(\frac{L_{it}}{C_{it}})$$

Where: Y_{it} =deflated added value;

C_{it} =stock of capital in real terms;

L_{it} =number of employees.

Because of the use of logarithms, we dropped the observations with negative deflated added value.

4. Finally, TFP has been computed according to the following formula, i.e. supposing a Cobb-Douglas production function with constant return to scale:

$$TFP_{it} = \frac{Y_{it}}{(L_{it})^{\beta}(C_{it})^{1-\beta}}$$

TFP has been computed only for firms with positive deflated added value and with positive deflated capital stocks for all five years, i.e. 4171 firms out of the 4225 in the original sample.

The problems encountered in the construction of TFP are missing observation for many firms, data consistency across countries/years, i.e. systematic lack of variables (like labour cost); different accounting rules (a bit homogenised by the fact financial information come form a comparative firm data set) and effect of inflation and exchange rates on the values.

The sectors included in the analysis are at three-digit NACE 91 classification for the manufacturing sector. We include 21 sectors at two digit classification: total food and beverages (15), total tobacco (16), total textile (17), total clothing (18), total leather and leather goods (19), total wood products (20), total paper and paper products (21), total publishing and printing (22), total chemical products (24), total rubber and plastics (25), total non-ferrous production (26), total ferrous production (27), total ferrous products except machinery (28), total machinery products (29), total office machinery and computer (30), total electrical machinery n.o.c. (31), total radio, TV and telecommunication equipment (32), total medical equipment, measuring instruments and watches (33), total motor vehicles (34), total other transportation equipment (35), total furniture and other manufacturing industries (36).

11 Appendix 2: Data Source

Data on RJV: The sources are Cordis and Eureka databases. They differ in some aspects: the projects in Cordis are funded and co-ordinated by the European Commission while the projects in Eureka have a decentralised funding source and the research project is proposed and defined by the participants themselves. The research carried out within Cordis is pre-competitive research, while within Eureka research is oriented to the development of marketable products and services.

Data on firm: balance sheets from Amadeus database (1992-96).

Data on R&D expenditure, personnel and patents at the country level: R&D Annual statistics 1997, Eurostat; Firm R&D expenditure from the Worldscope database

Data on trade, wages at the country and sectorial level are form the OECD Stan database (1997).

12 Appendix 3

12.1 Variables construction for section 4

$R\&D_{t_0}$ is the investment in R&D at the manufacturing level at time t0 (1992), at constant 90 prices, and it is expressed in absolute value (R92) or relative to the country GNP ($RIG92$).

$RJVcoop$ is expressed by $RJVtot$, i.e. the number of RJVs per firm over the total number of RJVs over the programmes and by $SPIsize_{it}$, i.e. the product of the total number of partners of the firm by a dummy which is equal to 1 whether the number of RJVs per firm is greater than 1 and 0 otherwise.

Pat is the patent applications per sector and per country and it is expressed as growth rate over the period (PAG) or by the level at the beginning of the period ($PAT92$) or by the level at the beginning of the period relative to the sectorial European level ($PATEU$).

OP is defined as trade balance over added value at the sectorial level for each country at constant 90 prices (X-M/VA90).

$\Delta R\&Dempl$ is the growth rate of labour employed in R&D at the country level for the manufacturing sector (RAG).

$Skilli_{tn}$ is unit labour cost at the firm level over the sectorial wage at the country level.

$RJVsSect_i$ ($SECT$) is the number of RJVs per sector over the total number of RJVs.

12.2 Variables construction for section 5

The dummy D is equal 1 if the firms are symmetric and 0 otherwise. As indicator of asymmetries for each RJV has been considered the standard deviation of two measures: profit margin and return on total assets. The dispersion term has been computed on the average values over the period for all the firms participating to each RJV (for which these data are available). Then we considered different thresholds of asymmetries for each of the two indicators ranging from 1 to 7.

13 References

Adams, J.D. and Jaffe,A.B. (1996), "BoundIng the Effects of R&D: an Investigation Using Matched Establishment-Firm Data", *Rand Journal of Economics*, Vol. 27, N.4, Winter, pp. 700-721.

Aghion, P., and Howitt, P. (1998), "Endogenous Growth Theory", MIT Press, Cambridge.

Aitken, B., G.D. Hanson and A. Harrison (1994), "Spillover, Foreign Investment, and Export Behaviour", NBER Working Paper No. 4967, December.

Amir, R. and Wooders, J.(1997), "One-Way Spillovers, Endogenous Innovator/Imitator Roles and Research Joint Ventures", CORE W.P. 69 9727.

Baily, M.N., Hulten, C. and Campbell, D. (1992), "Productivity Dynamics in Manufacturing Plants", *Brooking Papers on Economic Activity: Microeconomics*, pp.186-267.

Barba Navaretti, Bussoli, Von Graevitz and Ulph (1999), "Information Sharing, Research Co-ordination and RJV Membership", Feem and SIRN, mimeo.

Battacharya, S. Glazer, J. and Sappington, D.E. (1992), "Licensing and The Sharing of Knowledge in Research Joint Ventures", *Journal of Economic Theory,* pp.43-69.

Baumol, W.J. (1993) "Entrepreneurship, Management and the Theory of Productivity", MIT Press, Cambridge.

Baumol, W.J. (1994) "Multivariate Growth Patterns" ch.3, "Capital Intensity and TFP Convergence by Industry in Manufacturing", in "Convergence of Productivity", W.J. Baumol, R.R. Nelson and E.N. Wolff, Oxford University Press.

Benfratello, L. and Sembenelli, A. (1999), A. "Impact of RJVs on Firms Performance", FEEM and Ceris, mimeo.

Bernard, A.B. and Durlauf, S.N. (1995) "Convergence in International Output", *Journal of Applied Econometrics*, Vol.10, pp.97-108.

Bernard, A.B. and Durlauf, S.N. (1996) "Interpreting Tests of Convergence Hypothesis", *Journal of Econometrics*, 71, pp. 161-173.

Bernard, A,B. and Jones, C.I. (1996a) "Comparing Apples to Oranges: Productivity Convergence and Measurement Across Industries and Countries", *The American Economic Review*, December, pp.135-146.

Bernard, A,B. and Jones, C.I. (1996b) "Productivity Across Industries and Countries: Time Series Theory and Evidence", *The Review of Economics* *and Statistics*, pp.135-146.

Bernard, A,B. and Jones, C.I. (1996) "Technology and Convergence", The Economic Journal, July, pp.1037-1044.

Blomström, M., Kokko, A. and Zejan, M. (1994), "Host Country Competition and Technology Transfer by Multinationals", *Weltwirtschaftliches Archiv*, Band 130, 521-533.

Bretschger, L. (1997), "International Trade, Knowledge Diffusion and Growth", *The International Trade Journal*, Vol.XI, N.3, Fall, pp.327-348.

Carraro, C. and Souberayn, A. (1997), "R&D Co-operation and Endogenous Firms locations", Note di Lavoro Feem, Milan.

Cassiman, B. and Veugelers, R. (1998), "R&D Cooperation and Spillovers: Some Empirical Evidence", mimeo.

Coe, D.T.and Helpman, E.(1995), "International R&D Spillovers", *European Economic Review*, 39, pp. 859-887.

Coe, D.T., E. Helpman and Hoffmaister,A. W. (1995) "North South R&D Spillovers", Centre for Economic Policy Research (CEPR) Discussion Paper Series, N.1133.

Colombo, M. (1995), "Firms Size and Cooperation: The Determinants of Cooperative Agreements in Information Technology Industries", *International Journal of the Economics of Business,* Vol.2, No.1, pp.3-29.

Cozzi (1998) "R&D Cooperation and Growth", mimeo, Cornell University and University of Rome 'La Sapienza'.

D'Aspremont,C and Jacquemin,C. (1988), "Cooperative and Noncooperative R&D in Duopoly with Spillovers", *The American Economic Review,* pp.1133-1137.

D'Aspremont,C and Jacquemin,C. (1990), "Cooperative and Noncooperative R&D in Duopoly with Spillovers: Erratum", *The American Economic Review,* pp.641-642.

De Fraja, G. (1990), "Strategic Disclosure of R&D Knowledge and Research Joint Ventures", University of Bristol, W.P. 25 278.

Dollar, D. and Wolff, E.N. (1994) "Capital Intensity and TFP Convergence by Industry in Manufacturing" in "Convergence of Productivity", W.J.Baumol, R.R.Nelson and E.N. Wolff, Oxford University Press.

Driscoll, J.C. and Kraay, A.C. (1998), "Consistent Covariance Matrix Estimation With Spatially Dependent Panel Data", *The Review of Economics and Statistics*, pp.549-559.

Eurostat (1997), "R&D Annual Statistics 1997", Luxembourg.

Geroski, P.A. (1992), "Antitrust Policy Towards Co-operative R&D Ventures", *Oxford Review of Economic Policy*, Vol.9, N.2, pp. 58-71.

Griliches, Z. (1973), "Research Expenditures and Growth Accounting," in Science and Technology in Economic Growth, B.R.Williams, ed., MacMillan Press, 1973.

Griliches, Z. (1979), "Issues in Assessing the Contribution of Research and Development to Productivity Growth", *Bell Journal of Economics*, Spring, Vol. N.1, pp.92-116.

Griliches, Z. (1985), "Productivity, R&D, Basic Research at the Firm Level in the 1970s", NBER WP 1547, Cambridge MIT, January.

Griliches, Z. (1991) "The Search for R&D Spillovers", NBER WP n.3678, Cambridge MIT, July.

Griliches, Z. and Mairesse, J. (1985) "R&D and Productivity Growth: Comparing Japanese and US Manufacturing Firms", NBER WP n. 1778, Cambridge, MIT, December.

Grossman, G. and Helpman, E. (1993) "Endogenous Innovation in the Theory of Growth", NBER WP n. 4527,Cambridge, MIT, November.

Harrison, A.(1996), "Determinants and Effects of Direct Foreign Investment in Cote d'Ivoire, Morocco and Venezuela".

Howells and Neary (1995) "Intervention and Technological Innovation", Mac Millan Press, LTD London.

Jaumotte, F. (1998) "Technological Convergence and Trade", mimeo Harvard University, November 30.

Jones, C. (1994), "Time Series Tests of Endogenous Growth Models", *Quarterly Journal of Economics,* pp.495-525.

Jones, C. (1995), "R&D Based Models of Economic Growth", *Journal of Political Economy*, 103, August, pp.759-83.

Kamien, M.I. Muller,E. and Zang (1992), "Research Joint Ventures and R&D Cartels", *The American Economic Review,* pp.1293-1306.

Kamien, and Zang (1992), "Competing Research Joint Ventures", *Journal of Economics & Management Strategy*, pp.23-40.

Konishi, Le Breton, Souberayn and Weber, S. (1997), "Endogenous RJVs", Note di Lavoro Feem, Milan.

Legros, P. and Matsushima, H. (1991), "Efficiency in Partnerships", *Journal of Economic Theory*, pp.296-322.

Lichtenberg, F.R.,(1995), "R&D Collaboration and Specialisation in the European Community", CEPR.

Mairesse, J. and Hall, B. (1993), "Analysis of Technological Productivity on a Sample of French Firms: a GMM Approach".

Mansfield, E (1961) "Technological Change and the Rate of Diffusion", *Econometrica,* 29 N.4,October, pp. 740-66.

Manski, C. (1993), "Identification of Endogenous Social Effects: Reflection Problem", *Review of Economic Studies*, 60(3), July, pp. 531-42.

Marin and Siotis (1999),"Why Does a Firm Join an RJV?", Feem and Carlos III, mimeo.

Martin, S. (1994), "Private and Social incentives to form R&D Joint Ventures", *Review of Industrial Economics*, 9:157-171.

Nishimizu, M. and Page, J.M.Jr (1982), "Total factor Productivity Growth, Technological Progress and Technical Efficiency Change: Dimensions of Productivity Change in Jugoslavia", *The Economic Journal* (92), December, pp. 920-936.

Roller, L.H. and Sinclair-Desgagne,B. (1996), "On the Heterogeneity of Firms", *European Economic Review*, pp.531-539.

Sherer, F.M.(1982), "Inter-industry Technological Flows and Productivity Growth", *The Review of Economics and Statistics*, Vol. LXIV, November N.4, pp.627-634.

Vonortas, N.(1997), "Co-operation in Research and Development", Kluwer Publishers.