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On the relationship between R&D and productivity: a Treatment Effect analysis.

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Abstract

This study uses firm level data from two detailed surveys of Italian manufacturing firms to study the relationship between R&D expenditures and productivity growth. The analysis considers the different contributions of various forms of R&D (product, process, internal, external in collaboration with universities, research centres and other firms) to Total Factor Productivity (TFP). Thus, this paper answers the call for more research on the links between a firm's external R&D and its productivity. In the cross-section econometric analysis, we estimate a Treatment Effects model based on the assumption that the decision to carry out R&D is endogenous. We found evidence supporting such a methodological approach.

The main results reveal a positive and statistically significant relationship between the detailed measures of R&D and TFP. It is noteworthy that among external R&D investments, only expenditures for projects run in collaboration with other firms turn out to be highly significant, while cooperation in R&D with universities does not seem to lead to productivity enhancements. Because of the public good nature of research, firms may resort to do R&D within laboratories run by universities only when the outcome of the research does not have important strategic consequences.

Key Words: total factor productivity, selectivity, Manufacturing, Firm level

JEL Classification: C21, C80, D24, O30.

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1 - Introduction

Technological progress is central in the literature on endogenous growth. The works by Romer (1986, 1990), Grossman and Helpman (1991), Aghion and Howitt (1998) *inter alia*, do not view technology as an exogenous factor but, rather, develop theories looking at the sources of technology, that is, those factors inducing economic agents to create intentionally new products or processes. The role of technology as a crucial factor for economic growth has begun recently to show its pervasive effects (Paul and Siegel 2001; Siegel, 1997; Siegel et al., 1997). Indeed, recent research shows that the transition from the mass production model to the "lean manufacturing" one can be successfully completed only if firms are capable to exploit the complementarities between their strategies, their structure and their managerial processes (Brynjolfsson and Hitt, 2000). While the literature has identified a number of ways in which technology can exert its beneficial effects on the economy, there is unanimous consensus on the positive role of Research and Development (R&D) as an input in the production of new products and processes and as a factor for productivity and economic welfare growth.

The empirical literature on the links between productivity and R&D is also broad and varied. Generally, these studies differ in terms of the level of aggregation (macro, industry, firm or plant level) of the analysis and present mixed evidence (Griliches, 1998). As Paul (2002) argues, in most productivity studies technical aspects have precluded the consideration of spillover effects arising from temporal, spatial and sectoral linkages, despite the potentially significant impact of such linkages on economic performance.[1] Although it has been widely recognized that spillovers arise when firms are engaged in research activities with external partners (see, e.g., Cassiman and Veugelers, 2002), a dearth of studies linking productivity and external R&D activity can be found in the literature.

This article uses firm level data from two detailed surveys, collected respectively in 1995 and 1998, of Italian manufacturing firms to study the relationship between R&D expenditures and productivity growth. More precisely, using the R&D Capital Stock model developed in Griliches (1979) this study considers the different contributions of various forms of R&D (product, process, internal, external in collaboration with universities, research centres and other firms) to Total Factor Productivity (TFP). In the cross-section econometric analysis, to evaluate the effect of R&D on productivity, we explicitly take into account the self-selection problem arising from the fact that the firms themselves decide whether they intend to carry out R&D or not. Failing to

[1] A recent exception is Los and Verspagen (2000), where both an unweighted and an industry weighted measured of indirect R&D stocks are constructed.

account for the determinants of the decision to engage in innovative activities would lead to an overestimation of the R&D effects (Pakes and Griliches, 1980; Griliches, 1990). Thus, because both surveys include firms that did not report any R&D expenditures, as suggested by Crepon, et al. (1998) we estimate a Treatment Effects model based on the sample selection analysis developed by Heckmann (1979).

The main results reveal a positive and statistically significant relationship between R&D and TFP. Such a result is confirmed when the more detailed measures of R&D expenditures indicated above are included in the analysis. It is noteworthy that among external R&D investments, only expenditures for projects run in collaboration with other firms turn out to be highly significant, while cooperation in R&D with universities does not seem to lead to productivity enhancements. Because of the public good nature of research, firms may resort to do R&D within laboratories run by universities only when the outcome of the research does not have important strategic consequences. For instance, firms may delegate to universities the implementation of quality controls that guarantee their products' compliance with minimum regulatory safety standards. However, the usual intellectual property rights and appropriability difficulties seem to indicate that for the firms in our samples, external R&D with universities is a particularly unattractive strategy to acquire a strategic advantage (Love and Roper, 2002).

The article is organized as follows. The framework of our empirical analysis is discussed in the next section, which is followed by an introduction to the Treatment Effect approach. The data used is described in Section 4, followed by the comment to the empirical results. A final discussion on the implications of our analysis is provided in the concluding section.

2 - The relationship between R&D and Productivity

Like most studies in the literature, we consider an augmented Cobb Douglas production function exhibiting constant returns to scale (Lichtenberg and Siegel, 1991):

$$Y = A\left(\prod_i X_i^{a_i}\right)K^b \tag{1}$$

where Y is a measure of production, A represents disembodied, Hicks-neutral, technological progress evolving at the exogenous rate λ: $A = A_0 e^{\lambda t}$; X_i are the traditional factors of production: labour, capital, materials and energy, α_i their elasticities, and K represents the stock of technology with elasticity b. From (1), assuming constant returns to scale and perfectly competitive factors markets, by taking logs and differentiating with respect to time, the following expressions, indicating the relationship between the growth rates of R&D and the firm's productivity measured both as labour productivity (*y)* and Total Factor Productivity (TFP), can be derived:

$$\dot{y} = l + \sum a_i \dot{x}_i + r\dot{K} - \left(1 - b - \sum a_i\right)\dot{l} \qquad (2)$$

$$T\dot{F}P = l + r\,\frac{\dot{K}}{Y} \qquad (3)$$

where lowercase indicates labour intensive variables. Both expressions have been estimated in previous studies, that found a robust relationship between R&D and productivity. For instance, Griliches (1980a) and Griliches and Mairesse (1984) for the USA, Odagiri (1983) for Japan and Griliches and Mairesse (1983) for France found returns to R&D ranging between 11% and 31%. Results are more heterogenous in studies using small samples and seem to depend on the econometric methodology (cross section, panel data etc) adopted (Mairesse and Sassenou, 1991; Nadiri, 1993).

More recent studies (e.g., Lichtenberg and Siegel, 1991; Hall and Mairesse, 1995; Crepon, et al.1998; Lööf and Heshmati, 2001), using more detailed databases, confirm the positive link between productivity and such measures as R&D outlays, percentage of sales from "innovative" products or number of patents. These results are particularly robust for the static relation between R&D measures and levels of productivity, while they are not for that between R&D and growth of productivity (Klette and Kortum, 2002). Returns to innovation in these studies center around the 30% value, although they were lower or non-significant over the 70's (Lichtenberg and Siegel, 1991; Nadiri, 1993).

Other studies, rather than viewing R&D as a homogenous activity, have analysed the effects on productivity of the different components of R&D. For instance, Link (1981b) and Griliches (1986) found an additional return for basic research, while the evidence in Griliches and Lichtenberg (1982) and Lichtenberg and Siegel (1991) reveals that company-funded, unlike federally-funded, R&D has a beneficial effect on TFP. Another important distinction is that between internal, *intra-muros,* and external expenditures in collaboration with other institutions such as other firms, universities etc. The literature has emphasised the importance of both types of expenditure, which can be considered, on the one hand, as substitutes but also, on the other, as complementary. The latter viewpoint has received recently a wealth of attention, due to the recognition that it has become increasingly difficult, even for large firms, to rely entirely on their own internal resources to implement successful research projects (Teece, 1992; Dodgson, 1994; Klette and Kortum, 2002). Indeed, cooperation in R&D enables firms to share the costs that a single firm would not be able to afford, to reduce the associated risk, to exploit economies of scale and scope and, more generally, to exchange complementary assets that often have a tacit nature (Freeman, 1991;Veugelers, 1997). Even taking all this into account, internal expenditures in R&D still play a crucial strategic role as they are used to build up a firm's "absorptive capacity". This refers to the efforts that a firm undertakes to enhance its ability to make use of the research results obtained by rivals through beneficial spillovers (Cohen and Levinthal, 1989; Kamien and Zang, 2000).

Furthermore, maintaining an internal activity of research may attract other innovating firms that are seeking partners for their projects (Tether, 2002). However, as the foregoing discussion indicates, the choice of the type of research partner generally depends on the objectives that the firm pursues. Partnerships with universities and research centres are created for long-term projects of a basic research nature, and they are often subsidised both at national and European level (Tidd et al. 1997; Tether, 2002). Such a subsidisation may create perverse effects, as firms are cognizant that cooperation with public partners will reduce their ability to fully appropriate the benefits of the research efforts. Hence, they may opt to enter into the cooperative relationship, as it enhances, at a low cost, their ability to keep abreast of the technological changes occurring in their line of business. However, firms may also be induced to both exert the minimum effort possible and select projects whose objectives have a low probability to change drastically their industry's market structure. This may explain the evidence from many existing studies according to which publicly funded R&D did not have any significant impact on productivity.

Finally, as Paul (2002) documents, many studies find that positive knowledge spillovers stimulating innovation and productivity are primarily intra-national, thereby suggesting the importance of opportunities available at the local level. This is particularly relevant for the case of Italy, where evidence has been found for the existence of "Regional Systems of Innovation" (RSI). These are defined as "the localized network of actors and institutions in the public and private sectors whose activities and interactions generate, import, modify and diffuse new technologies" (Evangelista et al., 2002). In particular, these authors find that the cluster of R&D-based innovative regions is made up of firms from the North West regions and from Lazio, where a large section of the Italian public R&D infrastructure is concentrated. These regions are characterized by a good scientific and technological infrastructure due to the high concentration of universities and public and private research institutions. Moreover, in another innovative cluster including the regions of Emilia-Romagna and Tuscany, whose industrial structure is dominated by small and medium sized firms operating in such industries as textile, clothing as well as in the mechanical and electronic sectors, the rate of innovation is positively affected by favourable context-specific conditions. These are represented by specialized business services, government-supported local agencies, technology-transfer agencies, private business associations etc. Although in this study we do not directly measure any positive spillover due to research activity conducted within a given region, we indirectly control for regional effects when we analyze the determinants of a firm's decision to conduct R&D.

Furthermore, in this article we take advantage of available data on the different components of total R&D expenditures to fill a gap in the existing empirical literature on the relationship of external R&D with changes in productivity. Indeed, to the best of our knowledge, no evidence exists on the effects of various measures of extramural R&D outlays on TFP. Furthermore, we provide estimates of the returns from internal, process and product R&D that are consistent with those from previous studies.

3 - Methodology

The estimation strategy is based on the R&D Capital Stock model from Griliches (1979), as further developed in Griliches (1990). From equation (3) and the hypothesis that R&D has a nil depreciation rate as suggested in Griliches (1980) and Griliches and Lichtenberg (1982), we have:

$$\frac{dK}{dt} = \dot{K} = R\&D\,, \tag{4}$$

$$T\dot{F}P = l + r\,\frac{R\&D}{Y}, \tag{5}$$

where the TFP, expressed in terms of average annual growth, is given by:

$$T\dot{F}P = \frac{\dot{Y}}{Y} - \sum a_i \frac{\dot{X}_i}{X_i}\,. \tag{6}$$

Equation (5) lends itself to be immediately estimated. However, the presence of a number of firms reporting zero expenditure in R&D creates a problem in the selection of the sample. Indeed, the choice of conducting R&D is endogenously taken by the firms, and failing to account for the determinants of such a decision leads to a bias in the estimates of the effects of R&D. Thus, we use a Treatment Effect model that consists of two stages. In the first, a Selection equation is estimated by running a Probit model on the dummy variable "DR", valued one if firm *i* reports a strictly positive R&D budget, and zero otherwise:

$$DR_i = g'W_i + u_i \tag{7}$$

where *W* is a vector of variables that drive firm *i*'s decision to invest in R&D and *u*~N(0,1). Equation (5) becomes:

$$T\dot{F}P_i = b'X_i + e_i\,, \tag{8}$$

where e~N(σ_e,1); X_i is a vector of regressors comprising different measures of R&S plus a number of dummy variables that captures firm's specific characteristics, namely dimension and geographical location. In the subsequent analysis, r denotes the correlation between u and e. When u and e are correlated, in the second stage the following model is estimated:

$$T\dot{F}P_i = b' X_i + b_l \, l_i(gW_i) \,. \qquad (9)$$

where $b_l = r s_e$, and $l_i = f(\hat{g}W_i)/\Phi(\hat{g}W_i)$ is the *inverse Mill's ratio* that is added to the structural equation. Thus, this procedure, which was adapted by Barnow, Cain and Goldberger (1981) to the treatment effect case, deals with the sample selection problem as one of an omitted variable. It is therefore analogous to that proposed by Heckman (1979), although the latter, in the second stage, only considers the sub-sample of cases that report a positive value of the dependent, rather than of an independent, variable. Therefore, in the Treatment Effect model, all cases are included in the second stage. The estimation procedure can be summarized as follows (Verbeek, 2000):

$$T\dot{F}P_i = \left[b' X_i \middle| DR_i = 1\right] \cdot \Pr\left[DR_i = 1 \middle| Wi\right] + \left[b' X_i \middle| DR_i = 0\right] \cdot \Pr\left[DR_i = 0 \middle| Wi\right] \qquad (10)$$

Table 1 provides a list of the variables used in estimating the model. The econometric procedure presented above constitutes a reduced version of those proposed by Crepon et al. (1998) and Lööf and Heshmati (2001), which are based on the multiple equations model developed by Pakes and Griliches (1980). In these works, the R&D expenditures regressor in equation (9) is replaced by a measure of R&D output (e.g. number of innovative products or patents). However, it has to be stressed that not all the research activity results in a patent, partly because the firms may want to maintain their know-how secret and partly because certain innovations are not patentable, although they may significantly contribute to productivity enhancements.

4 - Data Description

The data used in the present study derives from two consecutive surveys conducted by Mediocredito Centrale (www.mcc.it), an Italian investment bank, in 1995 and 1998, respectively. Both surveys requested information on the firms' innovative activity for the three years prior to their implementation, that is, 1992-94 and 1995-97. The *Mediocredito Centrale* surveys considered three types of data: 1) balance sheet data for the 1989-1994 period in the first survey and 1989-1997 for the second one; 2) data related to measurable company characteristics (employment, investment, R&D outlays, etc.) and 3) qualitative and scaled response data regarding the firm's competitive environment, group membership and position within the group, industry characteristics, etc. for both periods. Firms with less than 500 employees were selected using a stratification procedure made according to size, industry and geographical location. The entire universe of firms with more than 500 employees was contacted. The databases are recognized to be a statistically significant representation of the Italian manufacturing industry for the periods considered. In the 1998 survey questions were included that did not feature in the previous questionnaire. The samples comprise manufacturing firms with more than 10 employees.

For each firm, more than 500 variables are included, with balance sheet data for up to nine years (1989-1997) for the 1998 survey and up to six years (1989-1994) for the 1995 wave. Unfortunately, R&D expenditures were available only for three years (1995-97 and 1992-1994) in each survey. Furthermore, only a limited number of firms were comprised in both surveys, which led to the decision to conduct our econometric analysis on the two samples separately. Data from the first survey was used in Piga (2002) to study the strategic use of debt in vertical relationships, while the decision to conduct cooperative R&D and its antecedent decision to engage in R&D are jointly studied in Piga and Vivarelli (2003) using the 1998 survey.

To calculate the TFP average growth, we used a long difference approach where we consider the change between the years 1997 and 1995 for the sample from the 1998 survey, and the years 1994-1992 for the sample from the 1995 survey. Firms with a TFP growth rate measure outside the interval ±30% were considered outliers and eliminated from the sample. To reduce potential simultaneity problems, we used R&D expenditures only from the first year of the period under analysis, that is, 1995 and 1992. Overall, after accounting for missing values, we obtained a sample size of 2268 units for the period 1992-94 and 2215 for the period 1995-1997.

For the calculation of the *TFP* from (6), Gullikson (1995) suggests that when firm level data are used, Y is better represented by total sales than by such other measures as added value.[2] Capital, labour and materials and energy are the three production inputs taken into account for which we have balance sheet data. The growth of capital input was calculated by the growth rate of tangible assets net of depreciation. The items considered for the evaluation of the costs for material and energy were the costs for materials, for services and other costs. For labour, we calculated the variation in the number of non-R&D employees, weighted by the number of part-time workers, to avoid the double counting problem.

Indeed, as suggested in Griliches and Mairesse (1984), to evaluate the TFP the production factors should be considered net of any R&D cost, because failing to do so leads to underestimation of the R&D returns. Unfortunately, we do not have this information for the amount of tangible assets, materials and energy that were used specifically for R&D purposes.

[2] Sales are also used as a measure of output in Los and Verspagen (2000).

Thus, the coefficient ρ in (5) will be considered as a return in excess to the average remuneration of the traditional production inputs. Furthermore, in the evaluation of the *TFP* in (6), the coefficients α_i represent each factor's elasticity to production that, in perfect competition conditions, are equal to the shares of the total production value remunerating each factor. To work these out, for each firm in the two samples, the shares of labor costs and materials and energy costs over total costs were calculated for the initial and the final year, and then their average value was considered. The share of capital costs was calculated as a residual. All variables expressing monetary values from both the 1998 and the 1995 survey were deflated using, respectively, the 1995 and the 1990 indexes of inputs prices. The deflators for nine different industries were used: these were also disaggregated by geographical location to take into account differences between the input prices in the North West, North East, the Centre and the South of Italy.

The definitions of all the regressors used in both stages are reported in Table 1, while Table 2 provides a summary description of the two samples' composition. It show that the majority of firms operates in sectors K (Industrial Machinery), L (Electric and Electronic equipment; Instruments), J (metals and metallic products) and B (textiles and apparel), and that together they account for 40.2% of all the firms in the 1992-94 sample, and 36.8% in the 1998 sample. More than 40% of firms in both samples are based in the North West of Italy; however, the 1995 survey includes more than 50% of firms in the 51-250 class size, while the second survey includes a majority of small firms with 50 or less employees. Overall, the geographical compositions in the two samples is similar to the one reported in Evangelista et al. (2002) who use the Italian data collected for the European project known as the "Community Innovation Survey" comprising 22787 firms.

Descriptive statistics for the variables used in both stages of the estimation are reported, for the two samples, in Table 2 and 3 respectively. Table 3 shows that 1008 firms out of 2268 (44.4%) have reported strictly positive R&D expenditures amounting to 1.84% of 1992 total sales. Table 4 indicates that in the 1998 survey the number of firms engaged in R&D fell to 689 (31,1% of total), each investing on average 1.41% of their 1995 total sales. In the first period, the most R&D intensive sector is that of electrical and optical machines (2.49%), immediately followed by the mechanical machinery (2.2%) and the transportation industry (2.08%). In the second period the most R&D intensive sector is the chemical one (2.13%), followed by the previously mentioned sectors. Internal R&D expenditures is predominant in the mechanical machinery industry (over 70%) while the chemical and plastic product sector reports the highest level of external R&D expenditures. The less R&D intensive sectors are the traditional sectors of food and tobacco, shoes and leather, stone, clay and glass, and petroleum with less than 1.0% of total sales invested in R&D.

In the 1998 survey it is possible to break down external R&D expenditures in three categories: with universities, other research centres and other firms. Collaboration with universities is particularly intense in the electrical machines and optical sectors, and practically absent in the wood products, in the petroleum and in the stone, clay and glass industries. In the chemical sector collaboration is mostly made together with research centres. Cooperation with other firms is important in the chemical, the transportation and the industrial machinery sectors.

Product R&D generally exceeds its process counterpart by a factor of 1.7, although it has to be noticed that the food and tobacco and the petroleum industries invest more in process R&D. In both samples, the firms in the North-East and in the Centre are the most R&D intensive, while those in the South lag behind. However, the latter tend to seek the collaboration of universities, although the firms in the Centre of Italy spend more than the others in external collaborations, especially with other firms. No significant difference can be noticed with regards to the relationship between firm's size and R&D intensity, although small firms tend to invest more in external R&D, especially with other firms.

As far as the dynamic of productivity is concerned, the two periods present different performances. In 1992-94, the average TFP growth rate was 2.2%: it fell to -0.94% in the 1995-97 period. Among the industries that record results in contrast with the periods' average trend, the stone, clay and glass sectors registered a slow down in the first period (-3.1%) while the chemical (+1.6%), the petroleum (+0.5%) and shoes and leather (+0.3%) sectors are the only ones to record an increase in productivity in the second period. In both periods, the firms located in the North West of the country are associated with the best performance in terms of TFP, while small firms with less than 50 employees under-performed relative to their medium and large counterparts.

Finally, the economic rationales to construct the *W* matrix of the Selection equation (7) using the variables in Table 5, can be found in Piga and Vivarelli (2003).

5 - Results

Table 5 reports the estimates from the selection regressions for both samples. The estimates are generally consistent in both regressions and carry the expected signs. The negative and highly significant constants indicate that small firms located in the South of Italy operating in the Food and Drinks industry are less likely to report positive R&D outlays. Export intensity (EXPFATT) is positively associated with the likelihood to carry out R&D. Formal innovative activity is more likely found in larger firms (LNEMP) that are multiproduct (PRODDIVE) and have a greater proportion of intangible assets (INTASS) and of employees with a degree

(HUMLAU). The opposite seems to occur in those firms that concentrate their sales to the three main clients (MAIN3CL). Finally, the evidence suggests a tendency, for those firms belonging to a group, to concentrate their research at the holding firm level (HEADGR).

The estimates of the TFP treatment effect model for the 92-94 sample are reported in Table 6. As expected, greater expenditures in R&D are associated with a more intense growth of productivity. Quite interestingly, when total R&D outlays are broken down in internal – *intra-muros* – and external, the latter seems to have a greater effect on productivity, although internal R&D is characterised by a higher value of the *t*-statistics indicating that it is more likely to have positive and less variable effects on productivity. Finally, the estimates reveal that R&D investments aimed at the introduction or the improvement of existing processes improve productivity more than product R&D, although the latter's impact is statistically more significant.

These results are confirmed in Table 7 that reports the coefficients from the TFP treatment effects model for the 95-97 sample. A notable difference is that external R&D outlays now have both a greater coefficient and a higher *t*-statistic than internal R&D expenditures. More importantly, the estimates from the third model in Table 7 reveal that the impact of external R&D depends strongly on the characteristics of the research partner or collaborator. Indeed, the results suggest that doing R&D with other firms significantly enhances productivity (R&DOFS95), while collaboration with universities does not seem significantly associated with any productivity enhancement (R&DUNS95). Between these two extremes lies the impact of R&D expenditures within private or public research centres (R&DECS95), whose coefficient is positive and weakly significant. Overall, these estimates are consistent with the approach that views research as a public good. Indeed, they suggest that firms allocate their external R&D outlays in a way that maximizes the private return of the investment. That is, strategic research projects are shared with other private firms because the risk of appropriation of the research results by outside competing firms is reduced. More basic research that is unlikely to yield marketable products or more efficient processes in the near future but that may be nonetheless useful for maintaining a firm's absorptive capacity, is conducted with public, State-run universities. The incentives for research centres, even for public ones, to disseminate the results of their research activity is weaker than in universities, as they can exploit them for commercial purposes. Thus, firms are more willing to collaborate and share resources with research centres, as spillovers may be more easily internalised. From a more general viewpoint, our findings support the notion that spillovers arising from a firm's spatial and sectoral linkages, play a crucial role in shaping a firm's productivity growth (Paul, 2002).

Finally, the foregoing discussion of (9) indicated that unobserved characteristics included in ε_i may be correlated with the firm's voluntary decision to invest in R&D, which could introduce a sample selection problem. This seems to be the case in our two samples. Indeed, we could reject the null hypothesis of no selectivity bias in all our models, as the coefficients of λ are significant in both periods. The negative sign indicates the existence of unobservable characteristics that positively (negatively) influences a firm's decision to engage in R&D, but that negatively (positively) affects its productivity. Thus, the evidence from both surveys lends some support to our methodological choice to analyze the relationship between R&D and TFP using a Treatment Effect model.

6 - Conclusion

This study has investigated the links between a firm's productivity growth and its innovative activity, as identified by various measures of R&D expenditures (internal, external in partnership with other firms, universities and/or research centres, process and product). Our findings suggest two important conclusions. First, sample selection issues are found to be important when R&D is used to explain changes in productivity. Because many firms in our samples do not record any R&D expenditure, it was necessary to explain the process by which firms choose to invest funds for formal research. Thus, a two-stage Treatment Effect model was used in our empirical analysis, consisting of a first Probit regression to evaluate the characteristics of the selection process, and of a second regression to study the relationship between TFP and R&D. An interesting result from the Probit analysis regards the greater propensity of firms located in the North and the Centre of Italy to invest in R&D, probably reflecting the better technological opportunities available in those regions. Failing to account for these effects would result in biased estimates for the coefficient of R&D in the TFP regression. That is, if the sample selection issue were disregarded, in the TFP regression the effects of the determinants of the R&D decision would be confounded with the effects of R&D expenditures.

Second, the regression of TFP on external R&D expenditures revealed a non-significant impact of external research with universities, but a positive and significant coefficient for research carried out in partnership with other firms or research centres. This finding seems to suggest a strategy where firms use universities as partners mainly to carry out routine research activities with a low added value, such as compliance with regulatory quality standards. However, it is also important to bear in mind that such a result may be due to the limited time length over which we have analysed changes in TFP. Indeed, it is reasonable to expect that the more applied research conducted with other firms (customers, suppliers) may show its beneficial effects within a few years, while marketable outcomes from basic research with universities may fail to materialize even in the long run. However, research with universities has been found to increase a firm's internal "absorptive capacity" (Cockburn and Henderson, 1998). Thus, it may contribute to a firm's long-run viability because it enables a firm to keep abreast of scientific developments, thereby enhancing its possibility to take advantage of the technological opportunities available at the geographical and/or sectoral level.

Overall, our findings indicate that both internal and extramural R&D activities have a positive and significant impact on productivity. Similarly, R&D expenditures for improving or developing new products and/or processes yield significant and positive returns in line with those reported in other studies. Quite importantly, these results hold for two different samples, each covering a distinct time period (1992-1994 and 1995-1997, respectively), providing further support to the notion that innovation is one of the main driving forces guiding sustained economic growth.

TABLE 1
Variables Names and Description

TFPK__	TFP Average yearly Growth rate (**24**: 1992 – 94; **57**: 1995 – 97)
R&DS__	R&D expenditures over Sales (**92**: 1992; **95**: 1995)
R&DINS__	R&D expenditures in internal labs and structures over Sales (**92**: 1992; **95**: 1995)
R&DEXS__	R&D expenditures in external labs and structures over Sales (**92**: 1992; **95**: 1995)
R&DOFS95	R&D expenditures in external labs and structures owned by other firms over Sales (1995 only)
R&DUNS95	R&D expenditures in external labs and structures owned by Universities over Sales (1995 only)
R&DECS95	R&D expenditures in external labs and structures owned by research centres over Sales (1995 only)
R&DDS__	R&D expenditures aimed at the improvement and/or creation of products over Sales (**92**: 1992; **95**: 1995)
R&DCS__	R&D expenditures aimed at the improvement and/or creation of processes over Sales (**92**: 1992; **95**: 1995)
RESERVE	Ratio of accumulated Retained Earnings over Total Assets (1992; 1995)
HEADGR	Dummy=1 if a firm is the holding or controls other firms within a group organization (1992; 1995)
LNEMP	Size measured as the natural log of number of employees (1992; 1995)
INTASS	Ratio of 1994 Intangible Assets over Total Assets
DINF	Dummy =1 if firm invested in 1995-1997 to improve its Information Technology (IT) equipment.
COMPABR	Index of extent of competition from foreign firms measured as the square root of the sum of the three dummy variables specifying whether the main competitors are localised, respectively, in the European Union, in other industrialised countries and in developing countries.
MAIN3CL	% of total sales to the three main clients (1992; 1995)
PRODDIVE	Index of Product diversification= $1/(\Sigma s_i^2)$, s_i = Shares of sales from product group *i* (1995)
HUMLAU	Percentage of employees with degree or post-graduate qualifications (1992; 1995)
EXPFATT	Percentage of export sales over Total Sales (1992; 1995)
NWEST	Geographical dummy =1 if firm located in North West of Italy
NEAST	Geographical dummy =1 if firm located in North East of Italy
CENTRE	Geographical dummy =1 if firm located in Centre of Italy
SOUTH	Geographical dummy =1 if firm located in South of Italy
EMPL_	3 Dummy variables for size classes (**1**: 11≤x≤50; **2**: 51≤x≤250; **3**: 251≤x
IND D_	Industry Dummies (**A** – **N**):
	A: Food, Tobacco
	B: Textiles; Apparel
	C: Shoes, Leather
	D: Wood and wood products
	E: Paper; Printing
	F: Petroleum, Coal
	G: Chemicals
	H: Rubber, Plastics
	I: Stone, Clay, Glass
	J: Metals and metallic products
	K: Industrial Machinery
	L: Electric and Electronic equipment; Instruments
	M: Transportation
	N: Miscellaneous Industries: furniture, jewellery, musical instruments, toys.

TABLE 2
Descriptive Statistics: Samples composition by industry, location, size class, and R&d involvement

	1992-94		1995-97	
	n. obs.	% over sample	n. obs.	% over sample
	Region		**region**	
NEAST	735	32.4%	640	28.9%
NWEST	1039	45.8%	912	41.1%
CENTRE	345	15.2%	356	16.1%
SOUTH	149	6.6%	309	13.9%
	Industry		**industry**	
IND_DA	99	4.4%	239	10.8%
IND_DB	288	12.7%	317	14.3%
IND_DC	111	4.9%	82	3.7%
IND_DD	47	2.1%	62	2.8%
IND_DE	238	10.5%	145	6.5%
IND_DF	15	0.7%	9	0.4%
IND_DG	221	9.7%	114	5.1%
IND_DH	130	5.7%	145	6.5%
IND_DI	59	2.6%	141	6.4%
IND_DJ	250	11.0%	276	12.4%
IND_DK	284	12.5%	366	16.5%
IND_DL	340	15.0%	135	6.1%
IND_DM	158	7.0%	84	3.8%
IND_DN	28	1.2%	102	4.6%
	size		**size**	
DIP50	676	29.8%	1117	50.4%
DIP250	1237	54.5%	809	36.5%
DIP500	355	15.7%	291	13.1%
	R&D>0		**R&D>0**	
FILRES=1	1008	44.4%	689	31.1%

Variables' definition is in Table 1

TABLE 3
Descriptive Statistics of the 1992 – 1994 sample by R&D involvement

Entire Sample - N. obs=2268					R&D Sample - N. obs=1008				
	Mean	Std.Dev.	Min	Max		Mean	Std.Dev.	Min	Max
RESERVE	0.152	0.141	-0.228	0.880	RESERVE	0.141	0.131	-0.228	0.742
HEADGR	0.164	0.371	0	1	HEADGR	0.236	0.425	0	1
LNEMP	4.516	1.065	2.398	9.763	LNEMP	4.857	1.069	2.512	9.763
INTASS	0.021	0.044	-0.493	0.452	INTASS	0.024	0.049	-0.205	0.429
HUMLAU	0.033	0.058	0	0.652	HUMLAU	0.046	0.069	0	0.585
EXPFATT	0.310	0.298	0	1	EXPFATT	0.386	0.295	0	1
R&DS92	0.008	0.019	0	0.177	R&DS92	0.018	0.024	0.000	0.177
R&DINS92	0.007	0.017	0	0.170	R&DINS92	0.016	0.022	0	0.170
R&DEXS92	0.001	0.005	0	0.071	R&DEXS92	0.003	0.007	0	0.071
R&DDS92	0.006	0.014	0	0.132	R&DDS92	0.012	0.020	0	0.132
R&DCS92	0.003	0.007	0	0.097	R&DCS92	0.006	0.010	0	0.097
TFPK24	0.022	0.055	-0.279	0.258	TFPK24	0.025	0.053	-0.279	0.253

Variables' definition is in Table 1

Table 4
Descriptive Statistics of the 1995 – 1997 sample by R&D involvement

Entire Sample - N. obs=2217					R&D Sample - N. obs=689				
	Mean	Std.Dev.	Min	Max		Mean	Std.Dev.	Min	Max
MAIN3CL	0.340	0.248	0	1	MAIN3CL	0.317	0.243	0	1
PRODDIVE	0.012	0.005	0.01	0.123	PRODDIVE	0.013	0.007	0.010	0.123
HEADGR	0.143	0.350	0	1	HEADGR	0.241	0.428	0	1
LNEMP	4.124	1.096	1.992	8.944	LNEMP	4.694	1.216	2.457	8.944
INTASS	0.017	0.035	0	0.473	INTASS	0.020	0.039	0	0.411
HUMLAU	0.047	0.071	0	0.845	HUMLAU	0.060	0.079	0	0.845
EXPFATT	0.305	0.303	0	1	EXPFATT	0.400	0.299	0	1
R&DS95	0.004	0.013	0	0.169	R&DS95	0.014	0.020	0.000	0.169
R&DINS95	0.003	0.010	0	0.143	R&DINS95	0.011	0.016	0	0.143
R&DEXS95	0.001	0.005	0	0.151	R&DEXS95	0.003	0.009	0	0.151
R&DECS95	0.000	0.004	0	0.144	R&DECS95	0.001	0.007	0	0.144
R&DOFS95	0.001	0.003	0	0.082	R&DOFS95	0.002	0.006	0	0.082
R&DUNS95	0.000	0.001	0	0.031	R&DUNS95	0.000	0.002	0	0.031
R&DDS95	0.003	0.011	0	0.169	R&DDS95	0.009	0.018	0	0.169
R&DCS95	0.002	0.005	0	0.078	R&DCS95	0.005	0.008	0	0.078
TFPK57	-0.009	0.047	-0.297	0.265	TFPK57	-0.008	0.048	-0.252	0.265

Variables' definition is in Table 1

TABLE 5
Probit Estimates of the Selection equation: "*Does the firm have a positive R&D expenditure?*"

	1992-94			1995-97		
	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio
CONST	-2.203	***	-11.819	-3.052	***	-16.569
INTASS	1.350	*	1.932	1.419	*	1.710
HEADGR	0.206	**	2.495	0.143		1.589
HUMLAU	2.971	***	5.129	1.877	***	4.356
EXPFATT	0.589	***	5.809	0.467	***	4.262
LNEMP	0.276	***	8.877	0.320	***	10.066
RESERVE	-0.481	**	-2.300			
MAIN3CL				-0.375	***	-2.869
PRODDIVE				11.517	**	2.142
DINF				0.474	***	6.225
NWEST	0.485	***	3.745	0.277	**	2.551
NEAST	0.410	***	3.241	0.299	***	2.891
CENTRE	0.347	**	2.479	0.357	***	2.960
Dep. variable	DR			DR		
n. obs.	2268			2217		
Chi sqr	465.21	***		484.10	***	
Pseudo R^2	0.4904			0.4898		

***, **, * Significant at the 1%, 5% and 10% level respectively. Includes 9 industrial dummy variables. Variables' definition is in Table 1

TABLE 6
TFP Estimates 1992 – 94

	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio
CONST	0.012	***	6.223	0.012	***	6.221	0.012	***	6.197
R&DS92	0.290	***	4.302						
R&DINS92				0.239	***	3.073			
R&DEXS92				0.599	**	2.453			
R&DDS92							0.260	***	2.949
R&DCS92							0.388	**	2.285
LAMBDA	-0.003	**	-2.061	-0.003	**	-2.079	-0.003	**	-2.107
Dep. Var.	TFPK24			TFPK24			TFPK24		
n. obs.	2268			2268			2268		
Adj. R^2	0.058			0.058			0.058		
F	14.88	***		13.69	***		13.59	***	

***, **, * Significant at the 1%, 5% and 10% level respectively. Includes 9 industrial dummy variables. Variables' definition is in Table 1

Table 7
TFP Estimates 1995 – 97

	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio	Coeff.	sig	t-ratio
CONST	-0.005	***	-3.142	-0.005	***	-3.123	-0.005	***	-3.121	-0.005	***	-3.147
R&DS95	0.364	***	4.330									
R&DINS95				0.282	***	2.668	0.272	**	2.496			
R&DEXS95				0.577	***	3.098						
R&DECS95							0.475	*	1.804			
R&DOFS95							0.709	**	2.381			
R&DUNS95							0.651		0.624			
R&DDS95										0.337	***	3.494
R&DCS95										0.446	**	2.170
LAMBDA	-0.003	*	-1.901	-0.003	*	-1.826	-0.003	*	-1.843	-0.003	*	-1.908
Dep. Var.	TFPK57			TFPK57			TFPK57			TFPK57		
n	2217			2217			2217			2217		
R2 adj	0.037			0.037			0.036			0.036		
F	8.67	***		8.09	***		6.95	***		7.91	***	

***, **, * Significant at the 1%, 5% and 10% level respectively. Includes 9 industrial dummy variables. Variables' definition is in Table 1

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