RD and productivity: In search of complementarity between research and development activities

Barge-Gil, Andrés and López, Alberto

Universidad Complutense de Madrid

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R&D and productivity: In search of complementarity between research and development activities*

Andrés Barge-Gil[†] Alberto López[‡]

Universidad Complutense de Madrid

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Abstract

The link between R&D and productivity has been widely analyzed. However, these innovation activities have been considered as a whole. This paper analyzes the differentiated effect of research and development on productivity and tests the existence of complementarity between these activities. We find evidence supporting the existence of a direct effect of both innovation activities. Most interesting, our results suggest that there is complementarity between research and development in determining productivity.

Key words: R&D, Productivity, Complementarity

JEL Classification: O33

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[†]Dpto. de Fundamentos del Análisis Económico II. Universidad Complutense de Madrid. email: abarge@ccee.ucm.es.

[‡]Dpto. de Fundamentos del Análisis Económico I. Universidad Complutense de Madrid. email: alberto.lopez@ccee.ucm.es.

1. Introduction

The determinants of productivity growth are of central interest to economists since a long time (see Syverson (2011) for a recent review of this literature). Since the seminal paper by Solow (1957), in which he concludes that capital and labor growth are unable to explain most of the productivity growth, innovation processes have been proposed as one of the main explanatory factors for the Solow residual (see Griliches, 1996). Accordingly, since the seminal paper by Griliches (1979), a large body of literature have focused on analyzing the relationship between innovation and productivity. Wieser (2005), Hall et al. (2010) and Hall (2011) present detailed surveys of the main contributions to this literature.

This literature points to a clear conclusion: R&D activities are major factors in explaining productivity differences across firms. However, these activities has been considered as a whole, although research and development are different activities.[1] As pointed out by Aghion and Howitt (1996): "*...the main distinction between research and development is that they are aimed at generating different kinds of knowledge. Research produces fundamental knowledge, which by itself may not be useful but which opens up windows of opportunity, whereas the purpose of development is to generate secondary knowledge, which will allow those opportunities to be realized.*" These activities do not only differ in purposes and knowledge bases, but also in the type of people involved and management styles (see Barge-Gil and López, 2011).

Besides this, over the past two decades, a lot of attention has been paid to the idea that different activities jointly determine firm performance, i.e., the existence of complementarity between activities. Vives (1990), and Milgrom and Roberts (1990) first introduced the concept of complementarity in industrial and organizational economics. Intuitively, two practices are complementary if the returns to adopting one practice are greater when the second practice is present.

[1] One strand of literature has analyzed the differential impact of firms' basic research on productivity (see, among others, Griliches, 1986; and Czarnitzki and Thorwarth, 2012). However, basic research accounts for a very low share of total R&D investments of firms (see Barge-Gil and López, 2011).

Following this perspective, a good number of contributions in empirical economics of innovation is focused on the study of complementarity in the innovation processes. A stream of this literature has focused on the complementarity between organizational changes and information and communication technologies (see, for example, Bresnahan, et al., 2002, and Bloom et al., 2012), and between organizational changes and skills (see, for example, Caroli and van Reenen, 2001). In another strand of literature, several papers address the analysis of complementarity between internal and external R&D (see, among others, Beneito, 2006; Cassiman and Veugelers, 2006; Lokshin et al., 2008; and Schmiedeberg, 2008). Finally, another interesting issue is the complementarity between different cooperation partners (see Belderbos et al., 2006). However, to our knowledge, the empirical analysis of complementarity between research and development activities has not been addressed.

To summarize, research and development are different, although related, activities. Therefore, it is worthy of analyzing the differentiated effect of research and development on productivity and the potential complementarity between these activities. From a theoretical perspective, Aghion and Howitt (1996) introduce a Schumpeterian growth model taking into account the distinction between research and development, and pointing to the complementarity between these activities. However, in spite of their importance, these issues have not been empirically analyzed so far.[2]

The contribution of this paper to the empirical literature on innovation and productivity is two-fold. First, we analyze the differentiated effect of research and development on productivity. Second, we analyze the relevance of the interactions between these activities in determining productivity. To study the complementarity hypothesis, we use the "productivity approach". In this context, the analysis is carried out in a framework where the production function is augmented with a set of variables representing the R&D activities of the firm.

[2] Related empirical literature include Czarnitzki et al. (2009), and Barge-Gil and López (2011). Czarnitzki et al. (2009) analyze the patent premium for research while Barge-Gil and López (2011) focus on the differentiated effect of research and development on innovation outputs. However, these papers neither analyze complementarity between research and development, nor their effects on productivity.

In this paper, we use a panel data set of Spanish firms for the period 2005-2009. This data set combines information from two different sources: (1) a panel of innovative firms (PITEC); and (2) information from the community survey on ICT usage in firms (ICT Survey).

The rest of the paper is organized as follows. Section 2 describes the empirical approach followed, Section 3 introduces the data and presents some descriptive analysis. Section 4 presents and discuss the estimation results. Finally, Section 5 concludes.

2. Empirical approach to test for complementarity between research and development

This section presents the empirical framework that is used to estimate the complementarity effect of research and development on firms' productivity.

Two practices are complementary if the returns to adopting one practice are greater when the second practice is present. In our context, the complementarity hypothesis implies that the productivity of firms with research activities that also perform development activities is higher than the productivity of other firms.

Regarding literature on complementarity, Athey and Stern (1998) present a detailed overview of the main empirical procedures for testing for complementarity. Following the terminology used by Mohnen and Röller (2005), there exist three main approaches for testing whether a group of activities is complementary: (i) the "correlation approach" (based on computing correlations among actions); (ii) the "adoption approach" (based on reduced form regressions with exclusion restrictions); and (iii) the "productivity (or direct) approach". Since the aim of this paper is to analyze the potential complementarity between research and development in determining firms' productivity, we use the third approach.

The "productivity approach" starts out with a performance equation (in our case, we examine this issue in the context of a production function). This approach leads to the estimation of a production function depending on traditional inputs (labor, capital and materials) and a set of variables representing the R&D activities of the firm. In addition, the implementation of this approach differs whether R&D is measured using discrete or continuous variables. In this section, first, we start describing a general production function. Next, we introduce two empirical frameworks to test for complementarity between research and development using discrete choice variables and continuous variables, respectively.

2.1. Specification of the production function

We start out from a general Cobb-Douglas production function:

$$Y_{jt} = A_{jt} K_{jt}^{\alpha_k} L_{jt}^{\alpha_l} M_{jt}^{\alpha_m} e^{\varepsilon_{jt}} \tag{1}$$

where Y_{jt} is the output of firm j in year t, and K_{jt}, L_{jt} and M_{jt} represent capital, labor and materials, respectively. A_{jt} is a firm-specific total factor productivity and ε_{jt} is an uncorrelated zero mean error term. We model the firm-specific productivity term (A_{jt}) depending on the firm specific R&D activities, a time-invariant term that accounts for the heterogeneity across firms (η_j) and and year-specific intercepts (λ_t).

Taking logs in expression (1), we can write:

$$y_{jt} = a_{jt} + \alpha_k k_{jt} + \alpha_l l_{jt} + \alpha_m m_{jt} + \varepsilon_{jt} \tag{2}$$

Following Klette (1999), we express the production function in terms of logarithmic deviations from a reference point within industry. This approach allows us to control for unobserved factors that are common to all the firms within an industry, such as price deflactors and industry rate of dissembodied technical change. Accordingly, expression (2) can be written as:

$$\widetilde{y}_{jt} = a_{jt} + \widetilde{\alpha}_k \widetilde{k}_{jt} + \widetilde{\alpha}_l \widetilde{l}_{jt} + \widetilde{\alpha}_m \widetilde{m}_{jt} + \varepsilon_{jt} \tag{3}$$

where lower-case letters ($\widetilde{y}$, $\widetilde{k}$, $\widetilde{l}$, and $\widetilde{m}$) indicate that the variable is measured as the log deviation from the industry mean (for example, $\widetilde{y}_{jt} = \ln(Y_{jt}) - \ln(\overline{Y_{it}})$ where $\overline{Y_{it}}$ is the mean output across firms in industry i in year t) and $a_{jt} = \log(A_{jt})$.[3]

[3] Industry breakdown is defined in Table A1 in Appendix A.

2.2. Testing for complementarity using discrete choice variables

In this case, we use discrete choice variables to characterize the R&D activity of the firm. Specifically, we model the productivity term depending on dummies indicating whether the firm has research and development investments, respectively. Therefore, we can write:

$$a_{jt} = \beta_r Research_{jt} + \beta_d Development_{jt} + \eta_j + \lambda_t \tag{4}$$

where $Research_{jt} = 1$ if firm j presents a positive amount invested on research activities at year t, and $Research_{jt} = 0$ otherwise; and $Development_{jt} = 1$ if firm j presents a positive amount invested on development activities at year t, and $Development_{jt} = 0$ otherwise.

Combining equations (3) and (4), we can write:

$$\widetilde{y}_{jt} = a_{jt} + \widetilde{\alpha}_k \widetilde{k}_{jt} + \widetilde{\alpha}_l \widetilde{l}_{jt} + \widetilde{\alpha}_m \widetilde{m}_{jt} + \beta_r Research_{jt} + \beta_d Development_{jt} + \eta_j + \lambda_t + \varepsilon_{jt} \tag{5}$$

For discrete variables the analysis of complementarity builds on the concept of supermodularity introduced by Topkis (1978). This approach was first used in industrial and organizational economics by Vives (1990) and Milgrom and Roberts (1990). In this case, to test the complementarity hypothesis, we need to derive an inequality restriction as implied by the theory of supermodularity and test whether this restriction is accepted by the data.[4]

To test the existence of complementarity between research ad development, we rewrite the production function in (5) to include four mutually exclusive dummy variables. From the dummy variables *Research* and *Development* we define four exclusive categories: firms that have both research and development investments (*Research&Development*), firms that have only development investments (*DevelopmentOnly*), firms that have only research investments (*ResearchOnly*), and firms that have neither research investments nor development investments (*NoResearch&Development*).

[4] This approach, widely used, has been applied, among others, by Cassiman and Veugelers (2006), Leiponen (2005), and Mohnen and Röller (2005).

Now, we can write:

$$\begin{aligned}\widetilde{y}_{jt} &= a_{jt} + \widetilde{\alpha}_k \widetilde{k}_{jt} + \widetilde{\alpha}_l \widetilde{l}_{jt} + \widetilde{\alpha}_m \widetilde{m}_{jt} + \gamma_{11} Research\&Development_{jt} + \\ &\quad \gamma_{01} DevelopmentOnly_{jt} + \gamma_{10} ResearchOnly_{jt} + \\ &\quad \gamma_{00} NoResearch\&Developmet_{jt} + \eta_j + \lambda_t + \varepsilon_{jt}\end{aligned} \tag{6}$$

The restriction that needs to be satisfied for research and development to be strict complementary can be written as:

$$\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00} \tag{7}$$

The production function is estimated using system GMM for panel data (see Arellano and Bover, 1995, and Blundell and Bond, 1998). This method allows us to account for unobserved heterogeneity and predetermined and endogenous variables. Lagged levels of inputs are used as instruments for the first differenced equations, while lagged first differences are used as instruments for the levels equations. The instruments used are detailed in the notes to the tables. Sargan test of the overidentifying restrictions and m_1 and m_2 Arellano and Bond (1991) test statistics for first and second-order serial correlation are reported for each estimate.

2.3. Testing for complementarity using continuous variables

Now, we turn to the case where continuous variables are used to measure the R&D activity of the firm. In this case, we assume that the productivity term depends on the R&D investments of the firm:

$$a_{jt} = \delta_r r_{jt} + \delta_d d_{jt} + \eta_j + \lambda_t \tag{8}$$

where r_{jt} and d_{jt} represent the log of research and development investments of firm j at year t, respectively. Consistently with equation (3), in our empirical specification we measure research and development investments as the log deviation from the industry mean:

$$a_{jt} = \widetilde{\delta}_r \widetilde{r}_{jt} + \widetilde{\delta}_d \widetilde{d}_{jt} + \eta_j + \lambda_t \tag{9}$$

where $\widetilde{r}_{jt} = \ln(R_{jt}) - \ln(\overline{R_{it}})$ with $\overline{R_{it}}$ being the mean research investments across firms in industry i in year t; and $\widetilde{d}_{jt} = \ln(D_{jt}) - \ln(\overline{D_{it}})$ with $\overline{D_{it}}$ being the mean development investments across firms in industry i in year t. Now, combining equations (3) and (9), we can write:

$$\widetilde{y}_{jt} = a_{jt} + \widetilde{\alpha}_k \widetilde{k}_{jt} + \widetilde{\alpha}_l \widetilde{l}_{jt} + \widetilde{\alpha}_m \widetilde{m}_{jt} + \widetilde{\delta}_r \widetilde{r}_{jt} + \widetilde{\delta}_d \widetilde{d}_{jt} + \eta_j + \lambda_t + \varepsilon_{jt} \tag{10}$$

For continuous variables, complementarity between two variables means that the incremental effect of one variable on the objective function increases conditionally on increasing the other variable, i.e. $\frac{\partial \widetilde{y}_{jt}}{\partial \widetilde{r}_{jt} \partial \widetilde{d}_{jt}} > 0$. In this context, complementarity is expressed by the interaction term between research and development investments ($\widetilde{r}_{jt} * \widetilde{d}_{jt}$).

$$\widetilde{y}_{jt} = a_{jt} + \widetilde{\alpha}_k \widetilde{k}_{jt} + \widetilde{\alpha}_l \widetilde{l}_{jt} + \widetilde{\alpha}_m \widetilde{m}_{jt} + \widetilde{\delta}_r \widetilde{r}_{jt} + \widetilde{\delta}_d \widetilde{d}_{jt} + \widetilde{\delta}_{rd} (\widetilde{r}_{jt} * \widetilde{d}_{jt}) + \eta_j + \lambda_t + \varepsilon_{jt} \tag{11}$$

A positive (and significant) estimate of $\widetilde{\delta}_{rd}$ suggests that firms that both invest more in research and development, also have a higher productivity. Therefore, a positive (and significant) estimate of $\widetilde{\delta}_{rd}$ is consistent with the idea that there is complementarity between research and development. Again, system GMM is used for the estimation of the production function.

3. Data and sample of firms

The data used correspond mainly to the *Panel de Innovación Tecnológica* (PITEC). The PITEC is a date base for studying the innovation activities of Spanish firms over time. The data come from the Spanish Community Innovation Survey (CIS) and the survey is being carried out by the INE (The National Statistics Institute). The PITEC consists of several subsamples, the most important of which are a sample of firms with 200 or more employees and a sample of firms with intramural R&D investments. Both subsamples have quite broad coverage.[5]

One of the main advantages of the PITEC is that it provides separate information on research and development activities of the firm. This information allows us to construct the (discrete and continuous) R&D variables introduced in the former section.

[5] The PITEC is placed at the disposal of researchers on the FECYT web site http://icono.fecyt.es/pitec/Paginas/por_que.aspx.

Moreover, the PITEC provides the necessary information for the estimation of a production function: sales, number of employees and investment in physical capital. Physical capital is constructed for each firm by cumulating the physical investments using the perpetual inventory method (see Appendix B for details). However, the PITEC does not have data on materials. We solve this problem using information on materials from the community survey on ICT usage in firms (ICT Survey).[6] Detailed definitions of all employed variables can be found in Appendix C.

As explained before, the data set used in this paper matches the PITEC and the ICT Survey.[7] We use information for the years 2005 to 2009 and for manufacturing and service sectors. After combining these data sources, few small-medium firms (firms with fewer than 200 employees) remain in the sample. This is due mainly to two facts. First, a sample of large firms (firms with 200 or more employees) is one of the main subsamples included in the PITEC. Second, ICT Survey comes in waves of cross-sectional data, where the same firms are not necessarily sampled wave after wave. Related to this, large firms are more likely to survive over the period analyzed and to participate and respond to questionnaires. Given this sample design, and to preserve representativeness, we focus on analyzing large firms. Our final sample covers a total of $1,562$ large firms when restricted to firms with at least four years of data. We have a total of $7,167$ observations (919 firms with five consecutive observations and 643 firms with four consecutive observations).

Table 1 gives some descriptive statistics of the key variables. In our sample of large firms, 29% of the firms have research investments, while this figure is higher for development investments (35% of the firms). Regarding the frequency with which firms combine research and development activities, a high number of firms (21%) perform both activities. Only 8% of the firms specialize on research activities, while 14% of the firms have only development investments. However, most of the firms (57%) are not engaged in any R&D activity.

[6] This survey is executed by national statistical offices. In Spain, it is carried out by the Instituto Nacional de Estadística (INE) under the name *Encuesta sobre el uso de Tecnologías de la Información y las Comunicaciones y del Comercio Electrónico en las empresas.*

[7] López (2012) first used the combination of these sources to explore the effect of information and communication technologies and organizational change on firms' productivity.

4. Empirical results

This section presents the empirical results for the differentiated effect of research and development on productivity and for the interactions between research and development using the two approaches introduced in Section 2.

Table 2 shows the results when discrete choice variables are used to measure R&D activities. First, estimate (1) in Table 2 presents the estimation of a production function with traditional inputs only (k, l and m). Estimated elasticities for these inputs show plausible values.[8] Moreover, these estimated coefficients are robust to the inclusion of R&D variables (see estimates (2) and (3)), and the results of the specification tests (serial correlation and Sargan tests) do not indicate any problem.

Second, estimate (2) presents the results from estimating the effects of dummies representing research and development without taking into account the existence of complementarity. In this case, expression (5) is the relevant equation to be estimated. We find that both research and development have positive and significant coefficients. Moreover, the two estimated coefficients are equal. Therefore, we find evidence supporting that both innovation activities have a similar effect on productivity.

Finally, estimate (3) presents the results for the complementarity between research and development using discrete choice variables. Now, expression (6) is the equation to be estimated. To test complementarity, we perform a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$ (see Cassiman and Veugelers, 2006, for a similar application). We find evidence supporting the existence of complementarity between research and development (p-value=0.039).

The second approach introduced in Section 2 uses continuous variables to test the existence of complementarity. Table 3 shows the results of this of this exercise. Again, the results of the specification tests do not indicate any problem.

Estimate (1) in Table 3 presents the results without taking into account the existence of

[8] Low and insignificant capital coefficient is consistent with traditional findings using GMM techniques (see Blundell and Bond (2000), and Griliches and Mairesse (1998) for a discussion about this problem).

complementarity (equation (10)). We find that both types of investments have a positive and significant effect. Again, research and development have a similar effect on productivity.

Coming back to the primary interest of this paper, estimate (2) in Table 3 shows the results of the equation (11). In this case, we include the interaction term between research and development investments in the productivity equation. Again, both research and development investments have positive and significant coefficients. Moreover, we find complementarity between these types of investments in achieving higher productivity: the estimated coefficient for the interaction term ($r * d$) is positive and significant (p-value=.

The potential endogeneity of R&D variables has not been discussed so far (estimates (1) and (2) in Table 3 show the results considering research and development investments to be exogenous variables). Estimates (3) and (4) in Table 3 show a first attempt at dealing with the endogeneity of research and development investments. These estimates include GMM-type instruments for research and development investments (the instruments used are detailed in the notes to the Table 3). Estimates (3) and (4) in Table 3 replicate the results in estimates (1) and (2) in Table 3, respectively, when research and development investments are considered endogenous variables.

Estimated coefficients of traditional inputs (k, l and m) are robust to this exercise. Regarding R&D variables, the effect of research increases when it is taken as endogenous (compare estimates (1) and (3)). While development coefficient becomes lower and is estimated more imprecisely (obtaining a high standard error) so that this variable loses its significance when it is considered to be endogenous (see estimate (3)). Finally, the complementarity effect vanishes (see estimate (4)).

Further research is needed to deal with the endogeneity of R&D variables. An important step forward would be to improve instrumentation (especially instruments for research and development investments).

5. Summary and conclusions

Academics and policy-makers have emphasized the importance of innovation as a contributor to long-term productivity growth. In recent years, the role of different investments and their complementarity has been emphasized. However, in spite of its importance, this literature does not take into account an important element of heterogeneity: the distinction between research and development and the potential complementarity between them.

The contribution of this paper to the literature on innovation and productivity is two-fold. First, we analyze the differentiated effect of research and development on productivity. Second, we analyze the relevance of the interactions between these activities in determining productivity. In doing this, we use a unique data base of Spanish firms for the period 2005-2009. This data base provides separate information on research and development activities of the firm. This information, seldom available, is essential to this study. Our final sample includes $1,562$ large firms (firms with 200 or more employees) from manufacturing and service sectors.

To test the complementarity hypothesis, we use the "productivity approach". In this context, the analysis is carried out in a framework where the production function is augmented with a set of variables representing the R&D activities of the firm. The final specification of the production function and the complementarity testing strategy differ whether R&D variables are measured as discrete or continuous variables.

To summarize the results, first, when analyzing the "direct" effect of research and development on productivity, we find evidence supporting the existence of a "direct" effect of both innovation activities. This result is robust to the use of discrete or continuous variables to measure R&D. Second, the empirical evidence here suggests that there is complementarity between research and development. Again, evidence on complementarity is robust to the use of discrete or continuous variables to measure R&D. Therefore, the results here point out the role of the interaction between research and development activities.

Further research is needed to obtain a more conclusive evidence. In this sense, this paper can be improved in at least two ways. First, by improving the treatment for endogeneity of

R&D variables (mainly by improving instrumentation of research and development investments). Second, by analyzing whether differences in firms' characteristics (such as size and industry) affect the complementarity between research and development activities.

Appendix A. Industry breakdown

[Insert Table A1]

Appendix B. Construction of capital

Physical capital is constructed for each firm by cumulating the physical investments using the perpetual inventory method, starting from a presample capital estimate and using a depreciation rate equal to 0.1. We use the following perpetual inventory formula $K_t = (1-\delta)K_{t-1} + I_t$, where I_t is the investment in physical capital in year t, K_t is the capital stock in year t, and δ (=0.1) is the assumed depreciation rate. Initial capital stock is calculated following Hall et al. (1988) as follows $K_{t_0} = \frac{I_{t_1}}{\delta+g}$, where K_{t_0} is the initial capital stock, I_{t_1} is the investment in the first year available, and g is the presample growth rate of capital per year. In practice, we have characterized I_{t_1} as the firm's mean of the investment in physical capital for the observed period, and we use data of physical investments starting in 2003. Industry-specific presample growth rates of capital are defined using data of the mean gross fixed capital formation for the period 2000-2004 provided by the INE (the Spanish National Institute of Statistics). The industry breakdown provided by the INE is: Food products, beverages and tobacco products; Textiles and clothing; Leather and footwear; Wood and products of wood and cork; Paper, publishing, printing and reproduction; Coke, refined petroleum products; Chemicals and chemical products; Rubber and plastic products; Other non-metallic mineral products; Metal products; Machinery and equipment; Electrical machinery, apparatus and electronic components; Transport equipment; Other manufacturing products; Wholesale, retail trade and repair of motor vehicles and motorcycles; Hotels and restaurants; Transport and communications; Financial intermediation; Real estate activities and professional, scientific and technical activities; Other services activities.

Appendix C. Variable definitions

y: Log of sales of of goods and services.

k: Log of physical capital. Physical capital is constructed by cumulating the physical investments using the perpetual inventory method (see Appendix B for further details).

l: Log of number of employees.

m: Log of purchases of goods and services.

Research: Dummy which takes the value 1 if the firm presents a positive amount invested on research activities.

Development: Dummy which takes the value 1 if the firm presents a positive amount invested on development activities.

Research&Development: Dummy which takes the value 1 if the firm presents a positive amount invested on research and development activities.

DevelopmentOnly: Dummy which takes the value 1 if the firm presents a positive amount invested on development activities, but not on research activities.

ResearchOnly: Dummy which takes the value 1 if the firm presents a positive amount invested on research activities, but not on development activities.

NoResearch&Development: Dummy which takes the value 1 if the firm presents neither a positive amount invested on research activities nor on development activities.

r: Log of research investments.

d: Log of development investments.

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Table 1. Variable descriptive statistics[1]

Sample period: 2005-2009
No. of firms: 1,562
No. of observations: 7,167

	Mean	St. dev	Min	Max
y	18.22	1.34	12.56	23.23
k	16.54	2.16	6.95	23.28
l	6.29	0.89	4.48	10.63
m	17.43	1.88	7.81	23.19
Research	0.29		0	1
Development	0.35		0	1
Research&Development	0.21		0	1
DevelopmentOnly	0.14		0	1
ResearchOnly	0.08		0	1
NoResearch&Development	0.57		0	1
r	3.84	6.01	0.00	18.47
d	4.57	6.33	0.00	19.71

[1]Mean of the period 2005-2009.

Table 2. R&D and productivity
Testing for complementarity using discrete choice variables

Sample period: 2005-2009
No. of firms: 1,562
Dependent variable: y

Independent variables	(1)	(2)	(3)
k	0.070	0.062	0.052
	(0.062)	(0.061)	(0.053)
l	0.497***	0.473***	0.498***
	(0.134)	(0.134)	(0.140)
m	0.267***	0.281***	0.268***
	(0.075)	(0.073)	(0.119)
Research		0.054*	
		(0.030)	
Development		0.054*	
		(0.032)	
Research&Development			0.079
			(0.120)
DevelopmentOnly			-0.013
			(0.135)
ResearchOnly			-0.027
			(0.138)
NoResearch&Development			-0.038
			(0.140)
Complementarity test, p-value			0.039
m_1	-4.677	-4.811	-4.048
(p-value)	(0.000)	(0.000)	(0.000)
m_2	0.014	-0.014	-0.068
(p-value)	(0.989)	(0.988)	(0.945)
Sargan test (df=19)	21.817	20.192	18.279
(p-value)	0.293	0.383	0.504

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
Complementarity test is a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$. The p-value for this test is reported.
***significant at 1%, **significant at 5%, *significant at 10%.

Table 3. R&D and productivity
Testing for complementarity using continuous variables

Sample period: 2005-2009				
No. of firms: 1,562				
Dependent variable: y				
Independent variables	(1)	(2)	(3)	(4)
k	0.052	0.053	0.045	0.054
	(0.058)	(0.058)	(0.056)	(0.055)
l	0.544***	0.551***	0.622***	0.617***
	(0.119)	(0.118)	(0.123)	(0.117)
m	0.219***	0.221***	0.210***	0.221***
	(0.081)	(0.082)	(0.072)	(0.070)
r	0.006**	0.008**	0.011*	0.010
	(0.003)	(0.004)	(0.006)	(0.007)
d	0.007*	0.010**	0.002	0.005
	(0.004)	(0.005)	(0.006)	(0.008)
r*d		0.0006**		0.0003
		(0.0003)		(0.0009)
m_1	-4.613	-4.629	-4.922	-5.002
(*p*-value)	(0.000)	(0.000)	(0.000)	(0.000)
m_2	-0.289	-0.241	-0.459	-0.371
(*p*-value)	(0.773)	(0.809)	(0.646)	(0.710)
Sargan test (*df*)	20.724 (19)	20.965 (19)	35.399 (33)	43.071 (40)
(*p*-value)	(0.352)	(0.339)	(0.356)	(0.341)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
Estimates (1) and (2) consider R&D expenditures to be exogenous variables.
Estimates (3) and (4) consider R&D expenditures to be endogenous variable. These estimates include lagged levels t-2 and t-3 of the R&D variables as instruments for the differenced equations and lagged differences t-1 of the R&D variables as instruments for the levels equations.
***significant at 1%, **significant at 5%, *significant at 10%.

Table A1. Industry definitions

Manufacturing		Services	
Industry	NACE Code	Industry	NACE Code
Food products and beverages	15	Sale, maintenance and repair of motor vehicles	50
Tobacco products	16	Wholesale trade	51
Textiles	17	Retail trade	52
Wearing apparel; dressing and dyeing of fur	18	Hotels and restaurants	55
Leather and footwear	19	Transport	62
Wood and of products of wood and cork	20	Auxiliary transport activities; travel agencies	63
Pulp, paper and paper products	21	Post and courier activities	641
Publishing, printing and reproduction	22	Telecommunications	642
Coke, refined petroleum products	23	Real estate activities	70
Chemicals and chemical products	24 (except 244)	Renting of machinery and equipment	71
		Software consultancy and supply	722
Pharmaceuticals	244	Computer and related activities	72 (except 722)
Rubber and plastic products	25		
Ceramic tiles and flags	263	Research and development	73
Other non-metallic mineral products	26 (except 263)	Architectural and engineering activities	742
		Technical testing and analysis	743
Basic ferrous metals	27 (except 274)	Other business activities	74 (except 742, 743)
Basic precious and non-ferrous metals	274	Motion picture and video activities	921
Fabricated metal products	28	Radio and television activities	922
Machinery and equipment	29		
Electrical machinery and apparatus	31		
Electronic components	321		
Radio, television and communication equipment	32 (except 321)		
Medical, precision and optical instruments	33		
Motor vehicles	34		
Building and repairing of ships and boats	351		
Other transport equipment	35 (except 351)		
Furniture	361		
Games and toys	365		
Manufacturing n.e.c.	36 (except 361, 365)		
Recycling	37		