Tijdschrift voor Economie en Management
Vol. LII, 2, 2007

R&D, Innovation and the Impact on Productivity in Flanders

by D. CZARNITZKI and N. O'BYRNES

Dirk Czarnitzki
KULeuven, Department for Managerial Economics, Strategy and Innovation; Steunpunt O&O Indicatoren, Leuven and ZEW Mannheim (Germany)

Niall O'Byrnes
KULeuven, Department for Managerial Economics, Strategy and Innovation, Leuven

ABSTRACT

This paper presents an empirical study on productivity growth using data from the Flemish part of the Community Innovation Survey 2005. In particular, we investigate growth differences between R&D-performing firms and non-R&D performers. As internal R&D is only one source of innovativeness, we also consider growth contributions of product and process innovations. Using a sample of more than 1,200 firms in Flemish manufacturing and selected services, we find that R&D-performers show an almost 6%-points higher growth rate between 2002 and 2004 than non-R&D performers, on average. However, once product and process innovation are introduced in the model, the contribution of R&D drops to about 4%-points. Interestingly, we find that process innovations are an important driver of productivity growth while product innovations have no significant impact once it is controlled for R&D activity.

Keywords: Productivity Growth, R&D, Innovation, Flanders, Community Innovation Survey (CIS)

JEL-Codes: L10, O31, O32

I. INTRODUCTION

Since Schumpeter's seminal work on creative destruction of innovation, scholars in economics believe that technological change is one of the most important determinants of long-run productivity growth, which is essential for securing competitiveness at the firm-level and – as a result – of whole economies. Research and development (R&D) activities lead to the invention of new products, improve existing products or reduce the cost of producing existing products or services through the implementation of new technological discoveries. While successful R&D will contribute to productivity, it is a-priori unclear what the average pay-off of such activities will be due to the inherent risk associated with them. New knowledge accumulates in a way that is neither predictable, steady, nor continuous. While some innovation may come along by pure chance, other projects may have involved substantial investments that never led to any marketable result.

The incentive to undertake R&D activities in the business sector is motivated by the profits that are expected to flow from successful innovations. The risk of outcome associated with innovation activities, spurred scholars to investigate the relationship between innovative activities and productivity growth in numerous studies.

In this paper, we analyze productivity growth in Flemish manufacturing and selected service industries. Other strands of literature focus on the effects of R&D on the stock market value of firms. However, this approach is intrinsically limited in scope as only publicly traded firms can be analyzed (see Hall et al. (2005), for a recent study, or Czarnitzki et al. (2006) for a survey). Czarnitzki and Kraft ((2004a), (2006)) suggested to use corporate credit ratings to evaluate the financial returns to R&D, as credit ratings are unlike stock market values available for basically every firm in the economy. Other scholars have investigated the returns of R&D by using a return on sales or similar profitability measure as dependent variable (see e.g. Ravenscraft and Scherer (1982), or Czarnitzki and Kraft (2004b)). The vast majority of studies investigated productivity gains through R&D, though.

We employ the latest version of the Community Innovation Survey of the year 2005 to estimate production functions at the firm level. Beyond standard input factors such as labor and physical capital, we also account for R&D and innovation in order to estimate the growth contributions of the latter activities. In particular, we are interested to disentangle productivity growth effects of different dimensions of

R&D (subsidized and non-subsidized, permanent versus occasional R&D) and different kinds of innovations (product versus process innovations). The existing literature on R&D productivity focuses almost exclusively on measures of R&D, but does not differentiate among research activities and the actual introduction of new products or the implementation of new processes in production.

The remainder of the paper is organized as follows. The following section introduces the production function framework, briefly reviews existing literature, and ends with the model specification. Section III presents the data, and section IV the results. The final section concludes.

II. CONCEPTUAL FRAMEWORK AND MODEL SPECIFICATION

When the contribution of R&D to productivity is considered, econometric studies typically start from a production function, that is, an equation describing how factor inputs such as capital and labor are combined to produce output. A common functional form is of Cobb-Douglas type:

$$Y_{it} = Ae^{\lambda t} K_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\gamma} e^{\varepsilon_{it}} \tag{1}$$

where Y = real output, A = total factor productivity, K = the stock of physical capital, L = labour, R = R&D and e is the error term. The subscript i denotes firm and t is time. Typically the R&D variable is either measured as the stock of R&D capital or the investment in a given year. The total factor productivity (TFP) A denotes the output per unit of combined factor input, and is often estimated as a time trend or a constant in the regression model. Eq. (1) can be rewritten in logs as

$$\log(Y_{it}) = \log(A) + \lambda t + \alpha \log(K_{it}) + \beta \log(L_{it}) + \gamma \log(R_{it}) + \varepsilon_{it} \tag{2}$$

Scholars either estimate eq. (2) with cross-sectional data of firms, so that it can be shown that firms with higher R&D realize higher output, or they make use of time-series methods for estimation such that changes in the right-hand side variables induce change in Y. In the latter case, one would estimate eq. (2) either in first differences, or in terms of growth rates. In all cases, the parameters α, β, and γ represent the elasticities of output with respect to capital, labour and R&D. If, for instance, the estimate of $\gamma = 0.15$, and is statistically significantly different from zero one would conclude that a 10% increase in R&D results in a 1.5% increase in output (all else constant).

Through the functional form of eq. (2), it is implicitly assumed that the elasticity of output with respect to R&D is constant over firms (and through time). Therefore, other researchers specified a different equation to be estimated as they preferred to estimate the rate of return of R&D rather than the elasticity. This can also be derived from eq. (2) (see Griliches (1980), Griliches and Mairesse (1984)):

$$\frac{\Delta Y_{it}}{Y_{i,t-1}} = \lambda + a\frac{\Delta K_{it}}{K_{i,t-1}} + \beta\frac{\Delta L_{it}}{L_{i,t-1}} + \rho\frac{\Delta R_{it}}{Y_{i,t-1}} + \Delta\varepsilon_{it}, \tag{3}$$

where ΔR is the net investment in R&D capital, and ρ the rate of return to R&D.

Table 1 shows an overview of studies that relate R&D to productivity at different levels of aggregation. The core of the empirical literature on R&D consists of studies on the private return to R&D. These studies are usually divided into two types, cross-sectional and combined cross-sectional time-series, i.e. panel data. The cross section studies look at either a number of firms or a number of countries and try to measure their productivity return due to R&D in a single point of time. The time-series studies try to measure the change in the productivity over time relative to inputs and so determine its effect. A listing of a number of these studies is detailed in Table 1. The relationship between productivity and R&D is usually stated as elasticity and is defined as a percentage increase in a variable in relation to a percentage change of the other. For example the Griliches (1980) study reports an elasticity of 0.07, so a 10% increase in R&D expenditure will be a 0.7% increase in the output.

The cross-section studies report higher rates of return and with greater certainty than the time-series studies. The cross-sectional studies consistently predict positive elasticities in the region of 0.10 and 0.20. Studies examining time-series data show weaker and smaller (0.02 to 0.15) results but are still positive. The macroeconomic studies show a much wider band of predicted rates of return and are probably due to the specification of the model and production function used to estimate the data. Reconciling the results of the cross sectional data with time-series data and the macroeconomic evidence are an area of intense research, but nearly all studies and all forms of studies show positive and significant rates of return to R&D.

TABLE 1

Empirical Studies on the Elasticity of Output with Respect to R&D

Selected Estimates of the Elasticity of Private R&D from firm level data

Study	R&D Elasticity	Sample
Griliches (1980)	0.03 - 0.07	39 U.S. manufacturing industries; 1959 to 1977
Schankerman (1981)	0.10 - 0.16	110 U.S. firms (chemical and oil industries); 1963 cross-section
Griliches and Mairesse (1984)	0.19	77 U.S. firms (scientific sectors); 1966 to 1977
Griliches and Mairesse (1990)		
Sample 1	0.25 - 0.41	525 U.S. manufacturing firms; 1973 to 1980
Sample 2	0.20 - 0.56	406 Japanese manufacturing firms; 1973 to 1980
Hall and Mairesse (1995)	0.05 - 0.25	197 French firms; 1980 to 1987, cross-sectional estimation
	0 - 0.07	197 French firms; 1980 to 1987, time-series estimation
Minasian (1969)	0.08	17 U.S. firms; 1948 to 1957
Griliches and Mairesse (1984)	0.09	133 U.S. firms; 1966 to 1977

Selected Estimates of the Elasticity of Private R&D from Studies Using Aggregate Data

Study	R&D Elasticity	Sample
Patel and Soete (1988)	0.61	United States (TFP); 1967 to 1985
Lichtenberg (1992)	0.07	98 countries (per capita output); 1960 to 1985
Coe and Helpman (1995)	0.23	G7 countries (TFP); a 1971 to 1990
Australian Industry Commission (1999)		
Subsample 1	0.02	Australia (TFP); 1975 to 1991
Subsample 2	0.14	Australia (output); 1975 to 1991
Verspagen (1995)	(0.02) - 0.17	14 industries in 11 OECD countries; 1973 to 1988
Griliches and Lichternberg (1984)	−0.04	27 U.S. manufacturing industries; 1959 to 1976

Source: Adapted from Congressional Budget Office (2005), Mairesse and Sassenou (1991), Mohnen (1992), Griliches (1992), and Australian Industry Commission (1995).

In this paper, we will estimate a slightly different version of equation (3), partly due to data availability. Rather than using the growth of R&D expenditure, we employ an R&D dummy variable (*RD*) indicating whether firm i has undertaken R&D in the period under consideration.

$$\frac{\Delta Y_{it}}{Y_{i,t-1}} = \lambda + a\frac{\Delta K_{it}}{K_{i,t-1}} + \beta\frac{\Delta L_{it}}{L_{i,t-1}} + \delta RD_i + \theta X_{it} + \Delta\varepsilon_{it} \tag{4}$$

The constant term in this regression, λ, now represents the growth of total factor productivity in the group of firms not performing R&D. We are interested whether R&D performing firms exhibit higher productivity growth rates, such that $\lambda + \delta > \lambda$, or, in other words, whether δ is positive and significantly different from zero. The matrix X denotes other variables that will be included in variations of the basic regression model.

While we start our empirical study with a basic regression model that includes only R&D as measure of innovative activity the firm engages in, we extend the analysis in several ways. First, we distinguish different types of R&D performers:

- On the one hand, we split the R&D-performers into firms that received subsidies for their projects and those that did not. As often pointed out in the literature on evaluation of public policy (see e.g. David et al. (2000), for a survey and for more recent studies Almus and Czarnitzki (2003), Czarnitzki and Licht (2006), Czarnitzki et al. (2007), among others), governments follow a so-called "picking-a-winner" strategy when selecting innovation projects for subsidization, that is, among a variety of subsidy applications, governmental agents will select those that have the highest expected returns. Actually, project proposals addressed to the Flemish government are rated with respect to feasibility and expected economic returns. If the selection of the governmental agents would indeed be consistent with "picking-the-winner", we would expect to find that subsidy recipients achieve higher growth rates than non-subsidized firms, on average.
- On the other hand, we split R&D-performing firms into two groups: firms that indicated that they conduct R&D on a permanent basis, and those that indicated to conduct R&D only occasionally. One would expect that permanent R&D leads to higher growth than occasional activities, because it is likely that permanent R&D performers devote a larger share of their resources to such activities

than occasional performers. Furthermore, continuous quest for new ideas and solutions may lead to economics of scope among projects so that there is some cross-fertilization among different research tasks. Firms that conduct R&D only when needed may not be able to generate such spill-overs among projects.

Second, we investigate whether it is actually pure R&D that leads to productivity growth or whether successful R&D measured through product and process innovations is more important for growth. We distinguish innovating firms from non-innovating firms in two dimensions: on the one hand, we consider firms that introduced at least one new or significantly improved product and, on the other hand, firms that implemented at least one new process in their production in the period under review. It is expected that both product and process innovation cause higher growth. It should be noted that innovations in the framework of the European innovation surveys is not necessarily a result of own internal R&D activity. Firms can also innovate through contracting out R&D, acquiring new technology such as machinery in combination with an innovation project, or the purchase of licenses or other intellectual property rights that are used to improve production processes or products.

III. DATA AND VARIABLES

The data used in this paper stem from two sources. Most firm level data are taken from the Flemish part of the fourth Community Innovation Survey (CIS4) and refer to the years from 2002 to 2004. The CIS covered the EU25 member states, Norway and Iceland using a largely harmonized questionnaire over countries. The Flemish data were collected by the Steunpunt O&O Statistieken at K.U.Leuven (see Czarnitzki (2006a) for a detailed description of the survey). Our sample covers the Flemish manufacturing sector and selected services, such as computer services, R&D services, other business related services, transport, and trade. The CIS data are supplemented with information from the Belfirst database which contains the annual account data of Belgian firms. In total, our sample consists of 1,267 observations. Table 2 displays descriptive statistics of the variables used in this study.

The dependent variable Y in our analysis, productivity growth, is measured as the percentage growth in total sales between 2002

TABLE 2
Descriptive Statistics (N = 1,267)

Variable	Mean	Std. Dev.	Min	Max
$\Delta Y_{it}/Y_{i,t-1}$	0,062	0,280	−0,620	2,037
$\Delta L_{it}/L_{i,t-1}$	0,042	0,217	−0,500	1,417
$\Delta K_{it}/K_{i,t-1}$	0,090	0,760	−0,904	6,212
AGE_i	30,537	25,265	1	170
RND_i	0,365	0,482	0	1
RND_i*GOV_i	0,150	0,357	0	1
RND_i*(1-GOV_i)	0,215	0,411	0	1
RND_CON_i	0,284	0,451	0	1
RND_OCC_i	0,087	0,282	0	1
$PRODUCT_i$	0,398	0,490	0	1
$PROCESS_i$	0,375	0,484	0	1

Note: 10 industry dummies omitted.

($: = t-1$) and 2004 ($: = t$). All variables are expressed in real terms, that is, currency units are adjusted by the GDP deflator. The average of $\Delta Y_{it}/ Y_{i,t-1}$ amounts to 6.2% in the sample (median growth is 3.4%).

The exogenous variables control for factor endowment of firms (labor and capital), R&D and innovation indicators as well as exogenous growth due to industry affiliation and age effects.

Average labor growth between 2002 and 2004 amounts to 4.2% and is measured by the change in number of employees. Accordingly growth in capital is 9%, on average. Again, the values are expressed in real terms, that is, values are adjusted by the GDP deflator. We include age as a control variable as younger firms may exhibit higher growth rates than older firms. On average, firms in our sample are about 30 years old. Age will be included as log(*AGE*) in the regressions to allow for a non-linear effect.

R&D activity of firms is measured as a dummy variable (*RND*) indicating whether firm *i* conducted own intramural R&D during 2002 and 2004. 37% of firms in the sample conducted R&D. R&D performing firms can be split into firms that received R&D subsidies from either local, national or European governments and those that did not receive any subsidy for their innovation activity. Subsidy receipt is indicated by a dummy variable, *GOV*, that is equal to one if the firm received public support and zero otherwise: 15% of firms conducted R&D and received R&D subsidies, and about 22% were R&D-performers that did not receive public support. Finally the differentiation among permanent R&D performers (*RND_CON*) and firms that undertake R&D occasionally (*RND_OCC*) yields that roughly 28% of firms indicated that they conducted R&D on a permanent basis, whereas 9% conducted R&D on an occasional basis.

With respect to the results of R&D activities (or other, broader innovation activity), we see that almost 40% of firms introduced at least one new product (*PRODUCT*) between 2002 and 2004. For process innovation (*PROCESS*), we find that about 38% of firms implemented at least one new process during the time under review. Product or process innovation are defined according to the Oslo-Manual, the European guidelines for collecting innovation data (see OECD and Eurostat (2005)).

Last but not least, we include 10 industry dummies that allow for heterogeneous growth across industries (see Table 4 in the Appendix A for an overview on the industry composition). Note that the inclusion of industry dummies in the growth equation refers to different trends in growth over industries. While industries, such as information and communication equipment may show a positive growth due to other factors than those already included in the regression, more negative business cycle effects may lead to reduced exogenous growth in other more mature industries, for instance.

IV. ESTIMATION RESULTS

A. *Basic regression results*

We estimate four versions of eq. (4). All models include the growth of labor and capital input as well as ln(AGE) and industry dummies as control variables. Model A estimates whether R&D-performing firms achieve a higher growth rate than other firms. Model B includes the dummy variables for successful introduction of at least one new product or the implementation of a new process in production in addition to the variables included in model A. Model C and D represent variants of model A: first, we investigate whether the growth of R&D-performers differs between firms that received public R&D subsidies in the corresponding period and those that did not. Second, model D splits R&D-performing firms into these that conduct R&D on a permanent basis, and those that indicated in the survey to conduct R&D only on an occasional basis.

We estimate all models with the ordinary least squares (OLS) estimator. Table 3 presents the results. All models have in common that a test on constant returns to scale in production is rejected. The F-tests at the bottom of the table show that the coefficients of labor and capital do not add up to one. Instead, we find decreasing returns to scale as is common in such estimations. Firms that would increase labor and capital do not gain a proportional productivity growth, all else constant. Furthermore, we find that neither the constant term is significantly different from zero nor that the industry dummies are jointly significantly different from zero as indicated by F-tests. Thus, there seems to be no unobserved, exogenous growth in the Flemish business sector that is not accounted for by the other structural regressors in the model.

Both labor and capital show a positive relationship to productivity growth. The older the firms are, the less they grow in terms of productivity, as indicated by the negative and significantly differently from zero estimated coefficient of ln(*AGE*).

The most interesting results stem from the different specifications with respect to R&D and innovation across models A to D. In model A, it turns out that R&D-performing firms achieve almost a 6%-points higher growth rate than non-R&D performers, on average. We can thus conclude that R&D in Flanders yields significant, positive returns as it has been found in studies for other countries (cf. Table 1). Note, however, that the magnitude of the effect is not directly comparable to the studies that investigated elasticities between R&D investment or stocks and productivity as we estimated a modified equation.

In model B, where dummies for product and process innovation supplement the specification, the contribution of R&D decreases to about 4%-points, but remains positively significant from zero. Interestingly, we find that process innovations result in a 5%-points higher growth rate. Surprisingly, product innovations do not contribute to growth. Thus, it seems to be more important to implement cost-reducing or quality-enhancing production processes than introducing new products to the market. It seems that the new product effect is already captured by the R&D dummy.

Models C and D are based on model A, but decompose R&D into four dimensions. In model C, we find that R&D is positively significant for both firms that received public innovation subsidies during the

TABLE 3

OLS Regressions on Productivity Growth in Flanders (2002-2004)

Variable	Model A	Model B	Model C	Model D
$\Delta L_{it}/L_{i,t-1}$	0.535***	0.530***	0.534***	0.534***
	(0.057)	(0.057)	(0.057)	(0.057)
$\Delta K_{it}/K_{i,t-1}$	0.027**	0.026**	0.026**	0.027**
	(0.013)	(0.013)	(0.013)	(0.013)
ln(*AGE*)	−0.028**	−0.028**	−0.028**	−0.028**
	(0.012)	(0.012)	(0.012)	(0.012)
RND	0.059***	0.043**		
	(0.016)	(0.019)		
PRODUCT		−0.019		
		(0.018)		
PROCESS		0.052***		
		(0.017)		
*RND*GOV*			0.075***	
			(0.025)	
RND(1-GOV)*			0.049***	
			(0.018)	
RND_CON				0.057***
				(0.017)
RND_OCC				0.062**
				(0.027)
Intercept	0.020	0.017	0.020	0.020
	(0.049)	(0.048)	(0.049)	(0.049)
F Test on joint significance of industry dummies	1.27	1.22	1.28	1.25
F Test on constant returns to scale	60.56***	61.74***	60.93***	60.48***
N	1,267	1,267	1,267	1,267
R^2	0.237	0.243	0.238	0.237
F-Test on model significance	11.32***	10.22***	10.55***	10.68***

Note: *** (**,*) indicate a significance level of 1% (5%,10%).
Standard errors in parentheses are heteroscedasticity-consistent.

period under review and those that did not. The estimated coefficient of R&D performers that were subsidized is higher (7.5%-points) than the coefficient of other R&D performers (4.9%-points). We also see tentative evidence that the funded firms actually achieve higher returns to their R&D projects as the governmental agents who review the project applications may follow a picking-the-winner selection process as outlined in Section II. However, an F-Test on differences among coefficients does not reject the null hypothesis that coefficients are equal: $F(1,1251) = 0.89$; p-value $= 0.3467$.

The final model D decomposes R&D-performers into firms that conduct R&D on a permanent basis and into occasional R&D-performers. Both coefficients are positively significant, and surprisingly an F-test does not reject the null hypothesis that both coefficients are equal: $F(1, 1251) = 0.03$; p-value $= 0.8726$. Thus, it seems to be sufficient to conduct some R&D to achieve higher growth rates than firms that do not conduct any R&D. For the distinction between occasional and permanent R&D performers, it seems to be necessary to have data on the level of R&D expenditure to differentiate between variance in the engagement in such activities. Another possibility that would deserve further research is to account for product life cycles. Firms active in product markets with short life cycles may have to engage in permanent R&D to survive, while companies in markets with long life cycles such as cement or basic metal production, for instance, may not have to innovate permanently (unless the pressure for cost reduction by process innovations is high). While these product market life cycles effects should partly be captured by industry dummies, a thorough analysis of this phenomenon would require more detailed data on actual products than we have available in the survey.

B. *Robustness tests, extensions and discussion*

We considered several variations of the specifications. On the one hand in order to verify our results, and on the other hand to investigate further aspects of productivity growth in Flanders.

As multicollinearity among variables might be a problem in estimating trustworthy standard errors in the regressions, we checked for collinearity among regressors (see Table 5 in the Appendix B). As typical in such studies there is some correlation between growth of labor and capital, and also between age and growth of labor. However, the correlation coefficients are only around 0.2, so that they should not impose problems in the estimations. As one simple test we excluded the age variable in the regressions, and it turned out that all findings remained stable.

Multicollinearity emerges as a problem in the regression model B, where the contribution of successful R&D measured through product and process innovation is analyzed. As shown in Table 5, the correlations among the different measures of innovation activities is between 0.5 and 0.6. As we did not find any effect of product innovations we investigated this further: if both the R&D and process innovation variable are omitted, we find a positive and significant effect of product innovation which amount to higher growth of 4%. An F-test, however, reveals that the effects of the R&D and process variable are not fully captured by the product innovation indicator. Thus, there seem to be positive effects of each activity, but with our current data we are not able to separate the individual effects from product innovation from R&D and process innovation. We also tried to decompose product innovations into two more distinct categories to reduce collinearity: the introduction of significantly improved products and market novelties. The latter may reflect more radical innovation, where the former just describes imitation or incremental innovation. 68% of product innovators indicated that they introduced a market novelty. However, the decomposition did not improve the results.

We also tested several other factors that, in the end, had no measurable impact on productivity growth. First, we included a set of dummy variables that allowed for heterogeneous growth rates among regions. The inclusions of four dummy variables to control for variations among the five Flemish provinces did no show any effect. Second, we employed measures for different competitive pressure in the firms' main product markets. A set of four dummy variables describes markets ranging from monopoly, over oligopolistic structure to highly competitive, but they were jointly insignificant in all regressions and were finally dropped from the specification.

Finally, we also checked whether the inclusion of sampling weights change any of our findings. As the CIS survey is a stratified random sample of firms in the economy, it is useful to take the different sampling probabilities for each firm into account. The sample weights were also adjusted for non-response which may weaken the representativeness of the sample (see Czarnitzki (2006) for details on the sampling procedure). All previous findings were confirmed, when sample weights were taken into account in the regressions.

V. CONCLUSIONS

This paper presents a study on productivity effects of innovation activities for a representative sample of Flemish firms in manufacturing and services between the years 2002 and 2004. The major novelty of the paper is that we account for a number of different measures of innovation in a Cobb-Douglas production function estimation for Flanders. Beyond a measure of R&D activities we consider also "successful" R&D as indicated by the introduction of new products or the implementation of novel processes in the production. Furthermore, we explore different types of R&D-performing firms in more detail.

The main finding confirms results found in previous studies for other countries. R&D has a positive impact on productivity. In particular, we find that productivity growth differs significantly among R&D-performing firms and others. While the average growth rate between 2002 and 2004 amounts to 6.2%, R&D-performers achieve a 5.9%-points higher growth rate.

Once, product and process innovations are introduced to the model the contribution of R&D drops to about 4%-points. We find robust results for the contribution of process innovation: firms that implemented at least one new production process realize about 5%-points higher growth than other firms, all else constant. Interestingly, product innovations have no independent effect beyond R&D and process innovations. This result may partly owe to multicollinearity among R&D, product and process innovations, but specification tests have shown that product innovations are not as important as R&D and process innovation.

Furthermore, we find tentative evidence that firms that receive subsidies for their R&D projects show higher growth rates than those that are not subsidized. This result can be explained with a "picking-the-winner" strategy by governmental agents who select the project proposals in the subsidy application process.

A distinction between permanent R&D performers and occasional R&D performers does not yield a difference in productivity growth rates. We believe that our R&D indicators are not detailed enough to investigate these different behaviors thoroughly. It would possibly require information on the growth of R&D expenditures of both types of R&D performers to establish a statistically significant difference in productivity gains.

Although our study finds strong results in favor of productivity growth generated by R&D and innovation activities at the firm level, there are many options for further research. First, it has been pointed out by many scholars that the degree of knowledge that spills over among firms conducting R&D plays a crucial role in firm behavior. On top of own internal R&D, firms may benefit from R&D conducted elsewhere if they maintain a sufficient absorptive capacity to make use of such knowledge. Since a seminal study by Mansfield et al. (1977) this has been discussed and investigated at length in the literature (see e.g. Griliches (1992) or Jones and Williams (1998)). Second, with respect to methodological problems our study is not without limitations. We are not able to control for a simultaneity bias with our current data. Scholars believe that R&D and productivity are mutually dependent, that is, productivity growth is a function of R&D, but in turn R&D investment may be a function of previous productivity growth as it may provide cash-flow that could be used for R&D. This belief stems from the fact that it may be difficult to finance R&D from external resources due to the uncertainty of outcome. Potential investors such as banks may be reluctant to finance risky investments such as R&D which leads to a financial constraints problem at the firm level (see Hall (2002) for a survey on this strand of literature or Czarnitzki (2006b) for a recent study). Therefore, R&D investment could be endogenous to productivity growth. In our case, this problem may be weakened as we only use an R&D indicator but not the amount of spending. However, smaller firms, especially the occasional R&D performers, may be deterred from R&D in the absence of external financial resources and could thus change their R&D status as response to the evolution of their productivity. While we cannot apply instrumental variable techniques with the present data as we only observe growth rates in a single cross-section of firms and are, hence, not able to construct lags to be used as predetermined variables, this problem can be investigated further as new waves of the Flemish CIS become available in the near future, and panel data can be exploited.

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APPENDIX A

TABLE 4
Composition of Industries

Industry	Industry definition according to NACE sectors
Textiles	17, 18, 19
Paper/Wood	20, 21, 22
Chemicals/Plastics	23, 24, 25
Metal	27, 28
Machinery/Vehicles	29, 34, 35
Electronics	30, 31, 32, 33
Other Industries	1, 14, 15, 16, 26, 36, 37, 40, 41, 45
Trade	50, 51, 52
Transport	60, 61, 62, 63, 64
Information Services	72, 73, 74.2, 74.3
Other Services	65, 66, 67, 74 (except 74.2, 74.3), 85, 90

APPENDIX B: CORRELATION MATRIX

TABLE 5

Correlation Matrix of Variables

	$\Delta Y_{it}/Y_{i,t-1}$	$\Delta L_{it}/L_{i,t-1}$	$\Delta K_{it}/K_{i,t-1}$	ln(AGE)	RND	PRODUCT	RND*GOV	RND_CON
$\Delta L_{it}/L_{i,t-1}$	0.4593	1.0000						
$\Delta K_{it}/K_{i,t-1}$	0.1734	0.2187	1.0000					
ln(*AGE*)	−0.1363	−0.1761	−0.0712	1.0000				
RND	0.1050	0.0426	0.0274	0.0699	1.0000			
PRODUCT	0.0650	0.0427	0.0321	0.1017	0.6156	1.0000		
PROCESS	0.1318	0.0642	0.0440	0.0824	0.5330	0.5065		
*RND*GOV*	0.0844	0.0346	0.0368	0.0493	–	–	1.0000	
RND(1-GOV)*	0.0497	0.0198	0.0002	0.0391	–	–	−0.2201	
RND_CON	0.0765	0.0236	0.0350	0.0793	–	–	–	1.0000
RND_OCC	0.0580	0.0370	−0.0096	−0.0093	–	–	–	−0.1943

Note: The correlations that are not presented are not relevant, as the corresponding variables are not used simultaneously in a regression.