Internal and External R&D and Productivity – Evidence from Swedish Firm-Level Data[1]

Karin Bergman[†]

Abstract

This paper uses a panel of Swedish manufacturing firms to examine the effects of internal and external R&D on total factor productivity over the period 1991-2004. The findings give some support to the notion of complementarity between internal and external R&D, especially in industries with high R&D intensities, and suggest that the employees' level of education is important for the firm's capabilities to absorb external R&D. However, external R&D is generally found to have a negative effect on productivity and internal R&D is only significant when not including interaction terms between internal R&D and external R&D or human capital.

Keywords: Internal R&D, external R&D, productivity, Sweden

JEL classification: D24, L24, O32

[1] The author is grateful for helpful comments and suggestions from Pontus Hansson, Martin Andersson, Johan Blomquist, participants at 'The 2010 Ratio Colloquium for Young Social Scientists: Understanding Firm Growth' in Stockholm, August 2010, participants at the National Conference in Economics in Lund, October 2010, seminar participants at the Research Institute of Industrial Economics in Stockholm, November 2010, and seminar participants at the Department of Economics in Lund.

[†] Department of Economics, Lund University, P.O. Box 7082, SE-220 07 Lund, Sweden, karin.bergman@nek.lu.se

1 Introduction

Numerous studies have examined and confirmed the importance of firms' internal research and development (R&D) for firm performance (see Wieser 2005 and Hall et al. 2009 for a review of the literature). However, firms do not carry out their entire R&D themselves; they also acquire external know-how. This acquired know-how can take the form of contracted R&D, collaboration with other firms or organizations, public material like patents or publications, the use of consultants or the hiring out of skilled personnel who then return with new knowledge. Moreover, firms' use of external know-how has increased significantly since the 1980s, making it gradually more important in the innovation process (Arora et al. 2001, Jankowski 2001, Bönte 2003, Howells et al. 2003).

This paper deals with external know-how in terms of contracted R&D where a firm pays someone else to perform the R&D. This notion of external know-how will henceforth be referred to as external R&D. There are several reasons for firms to use external R&D (Den Hertog and Thurik 1993, Cassiman and Veugelers 2006); for example, it allows firms to avoid taking all the risks of R&D themselves and to get around financial constraints. In addition, there is the possibility of enjoying spillovers, since new knowledge may come into the firm. However, the complementarities to the rest of the production, which it can achieve by doing the R&D itself, do not exist and information can spill out from the firm.

The objective of this paper is to investigate the productivity effects of internal and external R&D. There are several reasons why we should expect the productivity effects to be equal or to differ. Transaction cost theory stresses the substitutability between internal and external R&D, and points out that outsourcing of R&D is a way for firms to exploit the R&D capabilities of competitors, suppliers and other organizations and thereby enjoy the economies of scale associated with specialization (Pisano 1990). This reasoning would hence yield the same productivity effects from internal and external R&D. Moreover, Rigby and Zook (2002) use case studies to show how an open-market innovation strategy, i.e. a strategy to open up the innovation process to external knowledge flows, can improve the cost, quality and speed of innovation when the pool of ideas to choose from increases for those responsible for innovation. Still, to ensure that the know-how of the R&D project stays with the buying firm and does not leak to competitors, the contract between buyer and seller has to be very clear on which specific technologies the buying firm owns (Pisano 1990). The establishment of such a contract can be very costly, not least because of the uncertainty and

complexity of R&D projects. Therefore, Veugelers and Cassiman (1999) argue that outsourcing of R&D is more likely to occur for R&D projects that are of a generic nature and not specific to the firm. In this setting there are possibilities for specialization advantages which imply that outsourcing of R&D occurs for routine research tasks, and process rather than product innovations. If this is the case, then we might expect higher returns to external R&D than to internal R&D, because most studies examining the returns to process and product R&D find higher returns for process R&D (Hall et al. 2009). However, Hall et al. (2009) explain that this result might be due to the poor reflection of quality improvements in the price indices and/or that new products imply adjustment costs that lower productivity in the short run.

Nonetheless, firms are faced not only by the choice between make or buy, but also by the choice of make and buy. Veugelers and Cassiman (1999) discuss how the combination of internal and external R&D creates extensive scope for complementarities, e.g. in the sense that internal R&D helps to modify and improve the external technology. Moreover, internal R&D capabilities improve the ability of screening the available external projects. Cohen and Levinthal (1989, 1990) discuss the importance of a firm's 'absorptive capacity', the ability to understand and use external information, for the innovativeness of the firm. This absorptive capacity depends on the prior knowledge of the firm, which is influenced by the employees' knowledge and the firm's own investments in R&D. Concerning the employees' knowledge, it is not only how much and what kind of education the employees have that matters, but also their general awareness of where useful information can be found and who possesses the relevant knowledge. The importance of a firm's own investments in R&D is positively dependent upon the pace of technological development in a field, and on the complexity of outside knowledge.

The existing literature on productivity effects from internal and external R&D is quite limited, especially in regard to using the amount of expenditures on internal and external R&D rather than simple dummy variables for having internal and/or external R&D. The study in this paper uses R&D expenditures in a panel of Swedish manufacturing firms to examine the rates of returns to internal and external R&D. Because human capital is an important factor in determining a firm's absorptive capacity, the effect of the employees' level of education on these returns is also examined. The estimation is performed in two steps; a production function is estimated in the first step in order to calculate a measure of total factor productivity, which is then used in the second step. The findings give some

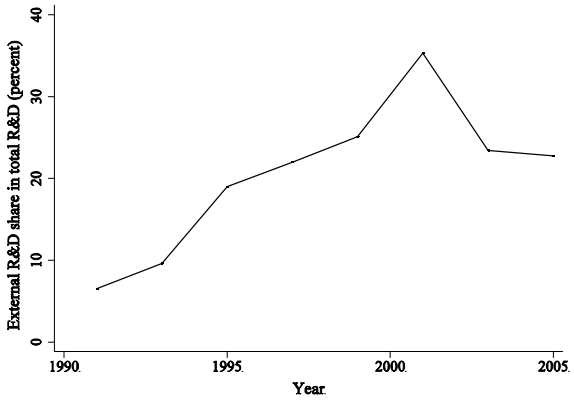
support to the notion of complementarity between internal and external R&D and suggest that the employees' level of education is important for the firm's capabilities to absorb external R&D.

The rest of the paper is organized as follows. Section 2 reviews the empirical evidence on internal and external R&D, section 3 describes the empirical analysis, section 4 contains the results and section 5 concludes the paper.

2 Empirical evidence

Following the international trend, the share of external R&D in total R&D increased in Sweden in the 1990s. This share went from a little over 5 percent in 1991, peaked at over 30 percent in 2001 and seems to have stabilized at around 20 percent in 2005 (see Figure 1), indicating a more pronounced role of external R&D.[2]

Figure 1. External R&D share in total R&D (percent). Manufacturing sector, Sweden, 1991-2005 (biennial data)



There are two strands of literature on the relation between internal and external R&D. The one strand studies whether internal and external R&D are complements or substitutes by examining a firm's decision to engage in internal and/or external R&D (see e.g. Veugelers 1997, Piga and Vivarelli 2004). The other strand studies the effects of internal and external R&D on a firm's innovative output or productivity (see e.g. Bönte 2003, Cassiman and Veugelers 2006, Lokshin et al. 2008, Schmiedeberg 2008, Santamaria et al. 2009).

In the first strand it is common to find that having internal R&D increases the probability of having external R&D, the interpretation often being that the two are complements. However, the results from the second strand give a more mixed picture of the complementarity issue.

[2] The large drop in the share of external R&D in total R&D from 2001 to 2003 might be a reflection of the dot com crisis which had a large impact in Sweden.

Cassiman and Veugelers (2006) find a positive effect on the share of sales from new products, in Belgian firms, for firms having internal and external R&D at the same time, specifically for firms with a high reliance on basic R&D. In contrast, Schmiedeberg (2008), in a study of German firms, finds no significant effect of having both internal and external R&D on either the probability of patenting or the share of sales from new products. Schmiedeberg's (2008) explanation of the lack of support for complementarity is that it might be due to the organization of production in Germany, where innovation strategies are oriented towards continuous, incremental innovation which might lead to a less market-responsive focus of external innovation strategies. Lokshin et al. (2008) use R&D expenditures to examine the impact of internal and external R&D on labour productivity in a six-year panel of Dutch manufacturing firms. They apply a dynamic panel data model that allows for decreasing or increasing returns to scale in internal and external R&D and for economies of scope. When not including squared R&D variables, there is no support for complementarity, but once they are included the interaction of internal and external R&D becomes highly significant and with a rather large estimated impact.

Concerning the direct effects of internal and external R&D on a firm's innovative output or productivity, Schmiedeberg (2008) finds, when examining different kinds of innovative output, that internal R&D is significant in all estimations, whereas contracted R&D is only significant for the probability of patenting, but with a larger estimate than for internal R&D. Cassiman and Veugelers (2006) find in some of their specifications that having only internal R&D gives a positive effect on the share of sales from new products, whereas only external R&D is never significant and shows up with opposite signs. Santamaría et al. (2009) investigate the effects of internal and external R&D on the probability of product and process innovations and on the production of patents. Also, they differentiate the effects in low and medium technology industries from those in high technology industries, and reveal that internal R&D has a positive and significant effect in all estimations except on the probability of process innovations in high technology industries. External R&D only has a small positive effect on the probability of a process innovation in low and medium technology industries, but is as important as internal R&D for the production of patents in high technology industries.

In the paper by Lokshin et al. (2008) internal R&D is significant and positive in all specifications and shows signs of decreasing returns to scale. In general, external R&D is not significant except when squared R&D variables are included in the model, and then only the

square of external R&D is significant and with a negative sign. Together with the positive effect of jointly having internal and external R&D, the results indicate that external R&D only has a positive effect when a firm has sufficient internal R&D. In contrast, Bönte (2003) shows, in a panel of West German manufacturing firms, that external R&D has a higher productivity effect than internal R&D. However, for high-technology firms the findings indicate that there are decreasing returns to scale to external R&D, and this result implies that productivity would decrease in his sample if the share of external R&D in total R&D increased.

In sum, the literature on the effects of internal and external R&D on productivity is quite limited and the results are mixed. Sometimes external R&D is found to have a larger productivity effect than internal R&D; sometimes the effect is smaller, and often not significant. Concerning the question of complementarity, the findings are also ambiguous. The results seem to differ depending on which sectors are examined and in what terms productivity is measured.

3 Empirical analysis

This section first describes the data that is used in the empirical analysis and then goes on to develop the model to be estimated. It also discusses issues pertaining to the estimation.

3.1 Data

The data for this study has been compiled by Statistics Sweden and covers the period 1991-2004. Several data sets have been merged. First, balance sheet data is extracted from the Structural Business Statistics (SBS) which cover most Swedish firms.[3] Second, data on R&D expenditures comes from the R&D statistics that are collected on a biennial basis and includes firms that have reported spending more than 5 MSEK on R&D in the SBS. In addition, this data set includes a sample of smaller R&D performing firms. From 1997 and onwards all firms with more than 200 employees are also included no matter the amount of R&D expenditures. The R&D data consists of 419-687 firms for each available year and covers, despite the sampling procedure, most of the R&D that is undertaken in Sweden.[4] In

[3] Before 1996 this dataset only includes firms with at least 50000 SEK in sales. From 1996 and onward most Swedish firms are included.

[4] When comparing the total amount of R&D in the R&D statistics with the reported R&D in the SBS (this data is only reported in intervals) the differences are very small for the years before 1996. Afterwards, the R&D statistics cover 70-80 percent of total R&D reported in the SBS. Moreover, the sample of R&D performing firms has generally not been affected by the sampling procedure of the SBS since the firms that are covered in the R&D statistics are the types of firms that were also covered in the SBS before 1996.

addition, this dataset allows for the differentiation between internal and external R&D. Third, data on the employees' level of education is taken from the education register.

Only manufacturing firms are used in this study since service firms in general cannot be fitted into a standard production function framework. The firms are grouped into 12 industry groups based on the Swedish standard of industrial classification, SNI 92, which corresponds to the ISIC rev (3) standard of classification. Some industries are on the two digit level and some are grouped together because there are very few firms in some industry classes. The industries that are grouped together are also quite similar in structure in terms of what they do and their R&D intensities.

As shown in Figure 3.1, the share of external R&D in total R&D increased in the 1990s in Sweden, but, as can be seen in Table 1, having only internal R&D is still most common for Swedish firms and there is no sign of a decreasing trend. Still, even if it is not explicitly shown in the table, it is possible to see that it is also very common to have both internal and external R&D. The small number of firms with only external R&D suggests that internal R&D is an important determinant of having external R&D, in line with previous findings in the literature.

TABLE 1

Number of firms with only internal or external R&D

Year	Only internal R&D	Only external R&D	Total number of firms with R&D
1991	171 (50 %)	15 (4 %)	340
1993	257 (57 %)	22 (5 %)	453
1995	261 (53 %)	19 (4 %)	489
1997	132 (45 %)	6 (2 %)	296
1999	165 (54 %)	8 (3 %)	303
2001	190 (60 %)	7 (2 %)	315
2003	189 (60 %)	11 (3 %)	316
Total	1365 (54 %)	88 (4 %)	2512

3.2 The model

Output (Y) at time t for firm i is produced using physical capital (K) and labour (L) in a Cobb-Douglas setting:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} \tag{1}$$

The variable A is a measure of total factor productivity (TFP) and α and β are the elasticities of output with respect to physical capital and labour. TFP, in turn, is a function of the R&D capital stock (R) at the firm and other external factors affecting productivity (E).

$$A_{it} \equiv TFP_{it} = R_{it}^{\gamma} E_{it}^{\sigma}$$

Taking logarithms and first differencing yields:

$$\Delta \ln TFP_{it} = \gamma \Delta lnR_{it} + \sigma \Delta lnE_{it} \quad (2)$$

In order to estimate equation (2), a measure of the R&D capital stock is needed. This stock variable is usually calculated using the perpetual inventory method. However, the biennial nature of the Swedish R&D data and the rather short time span make it problematic to employ this method. The calculation of the stock variable is also sensitive to the choices of rates of depreciation and growth of R&D (Hall et al. 2009). Therefore, taking the rate of return to R&D capital, $\rho = (\partial Y / \partial R)$, as the parameter of interest instead of the elasticity, $\gamma = \rho(R/Y)$, the expression $\gamma \Delta lnR_{it}$ can be rewritten as $\rho(\Delta R_{it}/Y_{it-1})$. Assuming no depreciation of R&D, ΔR_{it} can be approximated with the expenditures on internal and external R&D.

$$\frac{\Delta R_{it}}{Y_{it-1}} = f\left(\frac{R\&D_{it-1}^{int}}{Y_{it-1}}, \frac{R\&D_{it-1}^{ext}}{Y_{it-1}}\right) = f\left(r_{it-1}^{int}, r_{it-1}^{ext}\right)$$

The R&D expenditure variables are lagged one period because it is assumed that it takes time for R&D to affect productivity. Whether longer lags should be used is debatable; for instance, Ali-Yrkkö and Maliranta (2006) do not find a significant effect of R&D on productivity until after 3-5 years, but in general there is no consensus on the most appropriate lag structure (Hall et al. 2009). The most common is to use R&D intensity lagged one period only, and to find a significant effect at this level. Whether there should be different lag structures for internal and external R&D, depending on the type of R&D that is contracted out, is also open to debate. If, for example, the external R&D is more directed towards applied research, it could be that the results from external R&D will take more time to implement than those from internal R&D. In addition to the inclusion of the two different R&D variables in the estimation, there will be an interaction term between them to test for complementarity.

The additional set of controls, E, is a function of two variables. The first is a lagged TFP variable in order to allow for convergence in productivity levels, in the sense that lagging firms are more likely to be able to record strong productivity growth through technology

spillovers (Griffith et al. 2003). The second is a human capital variable, specified as the share of the employees with at least three years of higher education. The latter is also a measure of the absorptive capacity at the firm even if it does not say anything about the positions the educated workers hold. This variable, *H*, is included in the estimation both by itself and interacted with the R&D intensity variables to evaluate if the education level affects the returns to internal and external R&D. There are other factors that may affect the productivity at the firm, e.g. new knowledge spills over to the firm from neighbouring firms or contacts with customers or suppliers (see e.g. Arora et al. 2001), but spillover effects in this sense lie outside the scope of this paper. Hence, equation (2), for the growth rate in TFP, becomes:

$$\Delta \ln TFP_{it} = \phi_0 + \sigma_1 lnTFP_{it-1} + \rho_1 r_{it-1}^{int} + \rho_2 r_{it-1}^{ext} + \rho_3 r_{it-1}^{int} * r_{it-1}^{ext} + \sigma_2 H_{it-1} + \delta_1 r_{it-1}^{int} * H_{it-1} + \delta_2 r_{it-1}^{ext} * H_{it-1} + \mu_i + \nu_j + \lambda_t + \eta_{it}. \quad (3)$$

In addition to the extensions to equation (2) outlined above, equation (3) also includes a firm specific effect, μ_i, an industry effect, ν_j, a time effect, λ_t, and an idiosyncratic error term, η_{it}.

If the results show that $\rho_1 = \rho_2$ there is no difference in the productivity effects from internal and external R&D, and it would seem that the same kinds of R&D projects are performed internally and externally. If $\rho_3 > 0$, there will be evidence of complementarity between internal and external R&D in the sense that internal R&D enhances a firm's absorptive capacity.

3.3 Estimation

In order to estimate equation (3) a measure of TFP is needed. This measure can be obtained from the estimation of the production function in equation (1) in logarithms:

$$lnY_{it} = lnA_{it} + \alpha lnK_{it} + \beta lnL_{it}. \quad (4)$$

To allow for multilateral comparisons of productivity levels, TFP in one firm is measured relative to another firm. The general practice is to use the average of the other firms in the same industry (Van Biesebroeck 2007). The production function is hence estimated for each industry *j* separately and TFP in firm *i* in industry *j* at time *t* is then calculated as:

$$lnTFP_{ijt} = lnY_{ijt} - \overline{lnY_{jt}} - \widehat{\alpha_j}\left(lnK_{ijt} - \overline{lnK_{jt}}\right) - \widehat{\beta_j}\left(lnL_{ijt} - \overline{lnL_{jt}}\right), \quad (5)$$

where a bar over a variable denotes the mean of that variable in industry *j*, and $\widehat{\alpha_j}$ and $\widehat{\beta_j}$ are the estimated parameters from equation (4) for each industry *j* separately. The growth rate in TFP is then calculated as:

$$\Delta lnTFP_{ijt} = lnY_{ijt} - lnY_{ijt-1} - \widehat{\alpha_j}\left(lnK_{ijt} - lnK_{ijt-1}\right) - \widehat{\beta_j}\left(lnL_{ijt} - lnL_{ijt-1}\right). \quad (6)$$

When the measure of TFP is calculated the effect of internal and external R&D intensity on the growth rate of total factor productivity will be estimated. The reason for not directly including the R&D variables in the first step is the nature of the R&D statistics. Since this data is only collected on a biennial basis, the efficiency of the employment and capital estimates is increased by this two-step procedure. In both steps of the specification it is assumed that there is a firm-specific effect and a time effect and, as previously mentioned, there are also industry effects in the second step.

There are several problems to be considered in both steps of the estimation. First, there are time-invariant firm effects that may be correlated with the explanatory variables. Second, the independent variables are assumed not to be strictly exogenous, and third the panel data set has a short time dimension and a large firm dimension. The literature usually employs GMM methods to handle these problems, especially the difference GMM and more recently the system GMM proposed by Arellano and Bover (1995) and further developed by Blundell and Bond (1998). The system GMM uses a system of equations where lagged levels of variables are used as instruments for an equation in first differences and lagged first differences are used as instruments for an equation in levels. Blundell and Bond (2000) suggest that the system GMM is the most appropriate estimator when estimating first differences with weak instruments, and it has been shown to be a more reliable and robust estimator than the difference GMM when estimating production functions (see e.g. Ballot et al. 2001, Hempell 2005, Lokshin et al. 2008, O'Mahony and Vecchi 2009).

In the first step of the estimation all available data on firms that appear in the R&D statistics is used, even if they are not matched with the balance sheet data for the specific year that they are in the R&D statistics, and hence will not be in the second step of the estimation procedure. In this way the precision of the estimates for the elasticity of output with respect to physical capital and labour can be improved, especially since there are very few firms in some industry classes. In the estimation, output is measured as value added (deflated using industry-specific producer price indices), labour as the number of employees and capital as the book value of plant, construction and equipment (deflated with a construction price

index). Due to data limitations, it is not possible to correct labour and capital for R&D expenditures in order to avoid double counting. Both labour and capital could include R&D expenditures in the sense that some employees are R&D staff and some of the capital is used in R&D. Thus, the estimated rate of return to R&D can be interpreted as an excess return. Moreover, this rate of return will also be a gross rate of return since an estimation of the net rate of return implies assumptions about the depreciation rate and growth rate of R&D. Since the depreciation rate can be substantial at the firm level, due to replacement investments, the estimated rate of return will be underestimated (Hall et al. 2009).

Instruments for the estimation in the first step, using the system GMM, differ between the industries because of the results from the serial correlation tests and the Hansen test of overidentifying restrictions. Lagged level variables from t-2 or t-3 and later are used in the difference equation and lagged first differences from t-1 or t-2 are used in the levels equation. The number of lags in the difference equation depends on the number of firms in the estimation. Following the general rule of keeping the number of instruments to be lower than the number of groups in the estimation (see e.g. Roodman 2009b) all available lags are used for some industries and only one lag is used for others. To keep the instrument count down, a collapsed instrument set is used for most industries. With the use of these lags the sample for the estimation in the first step consists of 1110 firms and 11623 observations.

Instruments in the second step of the estimation procedure are first and/or second lagged levels of the right hand side variables in the first difference equations, and first differences dated t-1 or t-3 in the levels equation. Hence, in the second step the sample is reduced to 475 firms and 1740 observations. Table 2 shows the 12 industry groups and their respective means of internal and external R&D intensities in percent. The table reveals that internal and external R&D intensities vary quite a lot between industries and that, in general, external R&D intensities are much lower than internal R&D intensities. The sector including producers of radio, television and communication equipment has the highest internal as well as the highest external R&D intensity. It should also be noted that R&D in Sweden is very concentrated to a few firms, i.e. around two percent of the firms account for about 50 percent of the internal R&D expenditures.

TABLE 2

Internal and external R&D intensities (percent), by industry

SNI 92		Obs.	Mean internal R&D intensity	Mean external R&D intensity
15-16	Food, beverages and tobacco	104	7.03	1.13
17-19	Textiles, clothing and leather	28	4.61	0.16
20-22	Wood, paper and publishing	136	11.45	1.55
23-24	Refined petroleum; Chemicals	203	14.41	1.83
25-26	Non-metallic mineral products	119	8.06	0.41
27-28	Basic metals and metal products	139	5.25	0.41
29	Machinery and equipment	445	19.29	0.64
30-31	Computers and electrical	133	24.76	2.38
32	Radio, television and	69	63.90	18.07
33	Medical, precision and optical	166	34.74	2.37
34-35	Motor vehicles and other transport	159	31.00	3.97
36-37	Other manufacturing; Recycling	39	5.72	0.03
Total		1740	19.67	2.12

4 Results

The estimation of the production function in the first step produces an elasticity between 0.62 and 1.05 with respect to labour and between 0.06 and 0.19 with respect to capital, when significant. It should be noted that capital only is significant for five out of the twelve sectors, and in general the estimate is quite low. However, this result is not that unusual in within estimations (see e.g. Mairesse and Sassenou 1991), and in addition it could be that the book value of capital is not a good measure of the true value of capital at the firm. In the estimation there is no restriction on the returns to scale, but constant returns to scale are only rejected for one of the sectors – basic metals and metal products. TFP measures have been derived from the first step of the estimation (found in the Appendix) in order to be used in the second step; the mean growth rate is 2.87 percent. Table 3 displays descriptive statistics for the variables that are used in the two steps of estimations separately.

TABLE 3

Descriptive statistics of variables in both steps of estimation

	Variable	Obs.	Mean	Sd.	Min	Max
First step variables	Value added	11623	266466	925420	41	27300000
	No. of employees	11623	423	1091	1	19134
	Capital	11623	221334	820890	3	16200000
Second step variables	Growth in TFP	1740	0.03	0.32	-2.85	2.63
	TFP (log)	1740	0.11	0.43	-3.29	2.09
	Internal R&D intensity	1740	0.20	0.40	0.00	8.82
	External R&D intensity	1740	0.02	0.17	0.00	6.21
	Share of employees with higher education	1740	0.11	0.11	0.00	0.80

Value added and capital are expressed in thousands of SEK (2000 year prices).

Table 4 shows the mean growth rate in TFP divided according to R&D sourcing strategy. The highest growth rate is found among firms with only external R&D, but there are only 34 such observations. It is more interesting to see that the mean growth rate is slightly higher for firms with both internal and external R&D than for firms with only internal R&D.

TABLE 4

Growth in TFP by R&D sourcing strategy

	Obs.	Mean	Sd.	Min	Max
Only external R&D	34	0.074	0.196	-0.368	0.404
Only internal R&D	905	0.027	0.323	-2.846	2.180
Both internal and external	801	0.029	0.321	-1.648	2.631

Turning to the estimation results, Table 5 displays the results from the second step of the estimation where four different specifications are used in order to allow for comparisons with the existing literature. The first two specifications do not include any interaction variables, the third includes the interaction between internal and external R&D and the fourth also includes the interactions between R&D and the human capital variable.

To validate the estimations in the second step, the Hadri-Larsson test for stationarity (Hadri and Larsson 2005) is used on the residuals (from the second step) and the null hypothesis of stationarity cannot be rejected for any of the specifications. To further validate the system GMM estimator, both the OLS and the fixed effects estimator are also used since the coefficient of the lagged TFP variable in the system GMM should lie between those of the fixed effects and the OLS (Roodman 2009a). The results from these regressions, which are not displayed here, show that the coefficient of the lagged TFP variable lies inside the credible range; e.g. for the fourth specification the OLS estimate on lagged TFP is -0.27 and

the fixed effect estimate is -0.63. The GMM estimates for this variable are significant and negative in all specifications, and imply that about two fifths of the productivity lead is neutralized by the next period.

TABLE 5

Second step of estimation

Dependent variable: Growth rate in total factor productivity				
	(1)	(2)	(3)	(4)
$lnTFP_{t-1}$	-0.39***	-0.31***	-0.41***	-0.39***
	(0.120)	(0.091)	(0.111)	(0.107)
r_{t-1}^{int}	0.18***	0.26***	0.08	0.01
	(0.056)	(0.057)	(0.073)	(0.084)
r_{t-1}^{ext}		-0.14	-0.38*	-0.65
		(0.095)	(0.227)	(0.441)
$r_{t-1}^{int} * r_{t-1}^{ext}$			0.05**	0.08**
			(0.028)	(0.037)
H_{t-1}	-0.20	-0.31	0.09	-0.19
	(0.290)	(0.237)	(0.305)	(0.379)
$r_{t-1}^{int} * H_{t-1}$				0.40*
				(0.227)
$r_{t-1}^{ext} * H_{t-1}$				0.61
				(0.869)
Constant	0.04	0.04	0.05	0.06*
	(0.032)	(0.032)	(0.031)	(0.035)
Observations	1265	1265	1265	1265
Number of groups	475	475	475	475
AR(1)	8.12e-10	0	7.49e-10	3.07e-10
AR(2)	0.738	0.909	0.782	0.918
Hansen	0.368	0.708	0.601	0.481
Diff. Hansen	0.503	0.733	0.363	0.466
No. of instruments	52	69	76	105

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text.

Internal R&D is significant in the first two specifications and gives a rate of return of 18-26 percent, which is in line with the literature, especially since it is a gross rate of return and shows excess returns. External R&D has a negative sign but is only significant in column (3), indicating that having only external R&D is bad for productivity growth. This negative productivity effect might be due to the lag structure. As discussed in section 3.2, it might be that it takes more time for external R&D to affect productivity than internal R&D. Also, as discussed by Hall et al. (2009), if applied research is contracted out, it could be that firms

need to use resources to adjust to or implement the external R&D, which could result in a negative effect on productivity in the short run.

In both columns (3) and (4) it is clear that if a firm has both internal and external R&D, there are positive productivity effects, which supports the hypothesis of internal R&D being important for a firm's absorptive capacity, and shows the complementarity between the two sources of R&D.

The interaction terms with human capital are only significant, and on the 10 percent level, for internal R&D, which means that a firm gets higher productivity effects from internal R&D the more educated the employees are. However, the education level does not seem to help in absorbing the external R&D. The human capital variable in itself is never significant, a common result in within estimations since this variable does not change much over time (Hall et al. 2009). This characteristic might also affect the estimates of the interaction terms.

That the positive effect from internal R&D that we saw in columns (1) and (2) disappears in columns (3) and (4) is a bit discouraging, especially since the importance of internal R&D is well documented in the literature. However, it is probably the positive and significant interaction terms between internal and external R&D and between internal R&D and human capital that pick up this positive effect from internal R&D. Also, it is a general finding that the estimates of the rate of return are lower, and that it is more difficult to find significant estimates, in within estimations as compared to cross sections (Hall et al. 2009).

4.1 A deeper look at the results

To further investigate the results presented in the previous section two main routes have been undertaken. First the sensitivity of the results is examined in terms of the estimation of TFP and then the sensitivity of the results is examined in terms of outliers, the lag structure and the R&D sample. Table 6 summarizes the results from different estimations of TFP and Table 7 summarizes the rest of the sensitivity analysis.

4.1.1 Sensitivity to the estimation of TFP

Concerning the estimation of TFP, a two-step estimation procedure, like the one used in this paper can be criticised since the presence of measurement errors or problems in the first-step estimation is carried forward to the second step. Van Biesebroeck (2007) reviews ways of getting TFP estimates and checks their robustness against factor price heterogeneity, measurement errors and differences in production technologies. He finds that the system

GMM is one of the most robust estimators in the presence of both measurement error and heterogenous production technology. However, if productivity shocks are persistent, the semiparametric estimation method introduced by Olley and Pakes (1996) is more reliable. This method assumes that one part of a productivity shock in time *t* is observed by the firm, but not by the econometrician, and that the other part is not observed by either. At the beginning of each period, the firm observes this productivity shock and determines whether to exit the market, or to remain and make new investments in capital. With the sample of firms for this study it is not possible to get estimates for each industry *j* separately using this method. Hence, the first step is reestimated with all the firms simultaneously, now including industry dummies, with both this method and the system GMM. These two estimation methods produce very similar results. The results from the second step of the estimation with these two TFP estimates are shown in columns (1) and (2) in Table 6. Now that the first step is not estimated for each industry separately, the significance of the interaction term between internal R&D and human capital disappears, but the other variables are very similar to the ones reported in Table 5.

Another method of getting a measure for TFP, which is among the most robust ones, except if there are a lot of measurement errors, is an index number approach, like the Törnqvist index, which assumes constant returns to scale with respect to capital and labour in the production function in the first step and calculates the growth rate in TFP from the following equation:

$$\Delta \ln TFP_{ijt} = lnY_{ijt} - lnY_{ijt-1} - \frac{s_{ijt}+s_{ijt-1}}{2}\left(lnL_{ijt} - lnL_{ijt-1}\right) - \left(1 - \frac{s_{ijt}+s_{ijt-1}}{2}\right)\left(lnK_{ijt} - lnK_{ijt-1}\right), \quad (7)$$

where s_{ijt} is the cost share of labour in value added for firm *i* in industry *j* at time *t*.[5] The level of TFP for firm *i* at time *t* is given by:

$$lnTFP_{ijt} = lnY_{ijt} - \overline{lnY_{jt}} - \tilde{s}_{ijt}\left(lnL_{ijt} - \overline{lnL_{jt}}\right) - \left(1 - \tilde{s}_{ijt}\right)\left(lnK_{ijt} - \overline{lnK_{jt}}\right), \quad (8)$$

where $\tilde{s}_{ijt} = 0.5\left(s_{ijt} + \overline{s_{jt}}\right)$. It is only possible to calculate these TFP estimates up to 2002 due to data constraints. Moreover, the cost share of labour in value added is often higher than one, and excluding those observations reduces the sample by half. Estimating step two when TFP has been calculated using the Törnqvist index does not change the results compared to using system GMM in the first step, and then estimating the second step on this smaller sample, as

[5] Using the properties of the superlative index, the cost shares of labour in value added have been smoothed following Harrigan (1997).

shown in columns (3) and (4) in Table 6. However, the results are somewhat different in this smaller sample compared to the results presented in Table 5. Here external R&D is significantly positive by itself, and significant but negative when interacted with human capital. Moreover, the interaction between internal and external R&D is negative, but not significant. This sample of firms is characterized by lower R&D intensities than the full sample, something that will be further addressed in the next part of the sensitivity analysis.

TABLE 6

Different estimations of TFP

Dependent variable: Growth rate in total factor productivity				
	(1) Olley-Pakes	(2) System GMM	(3) Törnqvist	(4) System GMM
$lnTFP_{t-1}$	-0.45***	-0.44***	-0.35***	-0.28***
	(0.095)	(0.097)	(0.08)	(0.08)
r_{t-1}^{int}	-0.05	-0.02	-0.04	0.07
	(0.152)	(0.139)	(0.14)	(0.13)
r_{t-1}^{ext}	-0.54	-0.66	1.25**	1.31***
	(0.496)	(0.502)	(0.60)	(0.48)
$r_{t-1}^{int} * r_{t-1}^{ext}$	0.08*	0.08*	-0.03	-0.21
	(0.041)	(0.042)	(0.30)	(0.26)
H_{t-1}	0.08	-0.03	-0.16	-0.53
	(0.344)	(0.295)	(0.38)	(0.49)
$r_{t-1}^{int} * H_{t-1}$	0.36	0.38	0.15	0.12
	(0.561)	(0.541)	(0.30)	(0.32)
$r_{t-1}^{ext} * H_{t-1}$	0.34	0.65	-2.55*	-2.44**
	(1.045)	(1.034)	(1.30)	(1.14)
Constant	-0.01	0.03	0.04	0.07
	(0.042)	(0.040)	(0.05)	(0.05)
Observations	1274	1274	547	547
Number of groups	477	477	244	244
AR(1)	4.98e-08	1.83e-09	4.99e-06	9.50e-06
AR(2)	0.916	0.788	0.607	0.650
Hansen	0.335	0.342	0.646	0.584
Diff. Hansen	0.297	0.195	0.879	0.479
No. of instruments	105	105	89	86

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text except for column (4) where the second and third lags of lagged TFP are used as instruments instead of the first and second lags.

In sum, the results are not sensitive to the estimation of TFP in the first step, but there seems to be some sensitivity to the chosen sample.

4.1.2 Sensitivity to the investigated sample

Concerning outliers in the sample, there are no indications of outliers in the estimates of total factor productivity or in the human capital variable. However, for the R&D intensity variables there exist observations with R&D intensities above 100 percent. Removing the two observations that really look like outliers, with an internal R&D intensity over 800 percent and an external R&D intensity over 600 percent, makes no difference to the results, but when the 38 observations with R&D intensities between 100 and 500 percent are excluded, only lagged TFP is significant. Nonetheless, these observations mainly exist in those industries with the highest R&D intensities, and there is nothing particular about these observations indicating that there is reason to include them. The results from the estimation excluding R&D intensities over 100 percent are shown in column (1) of Table 7.

It is a common result that the rates of return to R&D differ between sectors (Hall et al. 2009). Hence, the next step is to divide the sample into industries with high and low R&D intensities following the mean internal intensities displayed in Table 2 so that the high R&D intensity industries are Machinery and equipment, Computers and electrical machinery, Radio, television and communication equipment, Medical, precision and optical instruments and Motor vehicles and other transport equipment. The results are displayed in columns (2) and (3) in Table 7. The first thing to note is that there is faster convergence for firms in high R&D industries. In general, the results for the high R&D intensity industries are very similar to the ones reported in Table 5. However, there are some differences in which variables are significant. External R&D is now significantly negative and the interaction between internal R&D and human capital is no longer significant. The negative estimate on external R&D could again be explained by the fact that it takes time to adjust the external R&D appropriately, and thereby we see this negative effect in the short run. Another similarity to the earlier results, which is not shown in the table, is that internal R&D is significant and of the same magnitude in specifications (1) and (2) as those presented in Table 5. The results for the low R&D intensity industries are very different, but similar to those obtained in the sample used when calculating the Törnqvist index. Here external R&D is positive and significant and the interaction between internal and external R&D is significantly negative. The implication of these results could be that firms that do not perform much R&D should outsource it, whereas firms with much R&D should opt for strategies including both in-house and outsourced R&D.

Two routes have been undertaken to examine if the results are sensitive to the lag structure. First the effect on the growth in TFP at time *t* of lagged TFP at time t-1, and lagged R&D variables at time t-3 is estimated, and then the effect on the average growth in TFP over three years of lagged variables at t-3 is estimated. The results from these estimations, shown in columns (4) and (5) in Table 7, are fairly similar to each other, except that lagged TFP is not significant for the average growth rate, and that human capital is positively significant for productivity growth three years ahead. However, the results differ from the ones reported in Table 5 in the sense that external R&D is again negative and significant, the interaction between internal and external is not significant and the interaction between external R&D and human capital is positive and significant. At this time horizon, internal R&D does not seem to increase the absorptive capacity whereas the education level of the employees does. Concerning the negative estimate on external R&D, these results show that it does not seem to be the lag structure that explains it. It could of course be that three years is still a short time horizon, but it is more difficult to explain the negative effect here.

The literature provides some possible explanations for the negative effect. Antonelli (1989) surveys the literature on profitability and R&D investments where the general theory is that, due to financial markets' reluctance to sponsor uncertain R&D projects, R&D expenditures are positively correlated with high profitability and liquidity. However, empirical research has found both positive and negative relationships. Antonelli (1989) explains a negative relationship with a failure-inducement hypothesis stating that firms facing declining profits and increasing competition invest in R&D to modify their production mix and market conditions. He also finds support for this hypothesis in Italian firms. In a context of declining profits it might be easier to find financing for the outsourcing of R&D, since a firm does not necessarily take all the risk of the R&D project itself. The negative effect of external R&D could then be explained by this argument. Johansson and Lööf (2008) investigate how a firm's R&D strategy, in terms of being a persistent or an occasional R&D performer, affects productivity and profitability, and find that occasional R&D has a negative effect indicating that firms choosing occasional R&D are those that have productivity problems. The firm that persistently performs R&D undergoes a learning process in which it develops routines for performing R&D as well as acquires experience in how to commercialize R&D results, at the same time as accumulating a stock of knowledge. Outsourcing of R&D is a much more occasional strategy than the performance of in-house R&D and it could be that it is not only

the absorptive capacity of internal R&D that is needed to absorb external R&D, but also a persistent outsourcing strategy.

TABLE 7

Summary of sensitivity analysis

Dependent variable: Growth rate in total factor productivity						
	(1) Outliers removed	(2) High R&D industries	(3) Low R&D industries	(4) Longer lags[a]	(5) Average growth in TFP over 3 years[b]	(6) Both internal and external R&D
$lnTFP_{t-1}$	-0.34***	-0.41***	-0.21***	-0.47***	-0.04	-0.43***
	(0.074)	(0.125)	(0.076)	(0.074)	(0.032)	(0.121)
r_{t-1}^{int}	0.09	0.02	-0.04	-0.01	0.13	0.20
	(0.099)	(0.102)	(0.315)	(0.096)	(0.082)	(0.150)
r_{t-1}^{ext}	0.33	-0.84**	1.98**	-0.78***	-0.43**	-1.39***
	(0.454)	(0.409)	(0.884)	(0.194)	(0.177)	(0.454)
$r_{t-1}^{int} * r_{t-1}^{ext}$	0.09	0.09**	-0.74*	0.18	0.04	0.12***
	(0.368)	(0.037)	(0.413)	(0.294)	(0.046)	(0.032)
H_{t-1}	-0.21	-0.08	-0.38	0.04*	-0.28	-0.14
	(0.292)	(0.443)	(0.282)	(0.024)	(0.212)	(0.307)
$r_{t-1}^{int} * H_{t-1}$	0.51	0.25	1.16	0.07	-0.08	-0.17
	(0.492)	(0.233)	(0.976)	(0.201)	(0.147)	(0.318)
$r_{t-1}^{ext} * H_{t-1}$	-0.78	1.09	-3.37	1.93*	1.11**	2.30***
	(0.827)	(0.780)	(3.352)	(1.160)	(0.490)	(0.819)
Constant	0.04	0.11***	0.02	0.17***	0.05**	0.01
	(0.032)	(0.041)	(0.035)	(0.048)	(0.024)	(0.075)
Observations	1227	713	548	946	522	459
Number of groups	464	258	218	392	226	189
AR(1)	0	3.81e-07	1.21e-05	2.91e-07	1.10e-06	1.96e-06
AR(2)	0.828	0.904	0.744	0.297	0.021	0.591
Hansen	0.478	0.489	0.760	0.768	0.456	0.422
Diff. Hansen	0.550	0.373	0.512	0.662	0.383	0.428
No. of instruments	98	103	96	91	73	105

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order in residuals, respectively. Hansen is the Hansen test of overidentifying restriction. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time and sector dummies included in all models. Instruments are discussed in the text except for column (5) where, due to the autocorrelation tests, only instruments lagged two periods are used in the difference equation. [a] Except for lagged TFP, t-1 actually denotes t-3. [b] t-1 actually denotes t-3.

As a last sensitivity check, I only examine those firms that have both internal and external R&D at the same time, since there are a lot of zeros in the sample, especially for the external R&D intensity. The results are displayed in column (6) in Table 7, and again external R&D is found to have a negative effect. Moreover, in this sample the absorptive capacity hypothesis is confirmed in terms of both internal R&D and the education level of the employees.

In sum, the results reported in this paper are somewhat sensitive to the chosen sample. Decreasing the variance in R&D intensities makes it more difficult to find significant estimates, and finding a negative effect from external R&D is common in many variations of the estimation except for low R&D industries where external R&D has a positive effect. The capacity of internal R&D and human capital for absorbing external R&D is clearly sensitive to the chosen sample.

5 Discussion and conclusions

This paper has examined the impact of internal and external R&D expenditures on firm productivity. Using Swedish data on manufacturing firms for the period 1991 to 2004, the results reveal a rate of return to internal R&D of 18-26 percent when no interaction variables are included. This finding is in line with the general literature on R&D and productivity. The positive effect of internal R&D becomes smaller and insignificant when including the interaction variables with external R&D and human capital, due possibly to this effect being picked up by one or both of the interaction terms.

The effect of external R&D on productivity is not completely clear, but most of the findings indicate that it is negative. This result has several possible explanations. First, it may be that it takes more time to see the positive effect because the outsourced R&D is directed towards product development, which implies a negative effect in the short run due to adjustment costs. Second, it may be due to the failure inducement hypothesis, according to which firms invest in R&D to counteract declining profits. Third, it may be that firms only outsource R&D occasionally, in which case the firm does not have the routines to do this in an efficient way or that it is a sign of productivity problems. However, the negative effect disappears when removing the observations with high R&D intensities. Then the estimate on external R&D is positive. Hence, for firms that do not perform much own R&D it may be a good strategy to outsource it in order to exploit the R&D capabilities of other firms, in line with transaction cost theory.

There is some support for internal R&D as being important for a firm's absorptive capacity and thereby enhancing the effect of external R&D. However, in line with previous findings, support for complementarity seems to be sensitive to which industries are investigated. The support for complementarity in high R&D intensity sectors is in line with the Cohen and Levinthal (1989, 1990) notion of absorptive capacity where they argue that a firm's internal R&D is more important in industries where there is faster technological change.

The findings also suggest that the employees' level of education is important for the firm's capabilities to absorb external R&D, especially in a longer time perspective and for firms with both in-house R&D and outsourced R&D. The results concerning complementarity between internal R&D and the employees' level of education are less clear.

The sensitivity of the results to the chosen sample highlights the need for more studies in this area. With more data and longer time spans it might be easier to disentangle contexts in which we find different results and when it is optimal for firms to outsource R&D. Specifically, the results of high versus low R&D intensity industries emphasize the differences of the effects between sectors. These differences do not necessarily exist only in this division of sectors, which points at the need for more studies on specific industries. It could be that the same industries in different countries are more similar than different industries in the same country, and examining the productivity effects of internal and external R&D in certain industries in several countries could be a possible route for future studies.

References

Ali-Yrkkö, J. and Maliranta, M. (2006). 'Impact of R&D on Productivity - Firm-Level Evidence from Finland'. *ETLA Discussion Papers*, No. 1031, The Research Institute of the Finnish Economy, Helsinki.

Antonelli, C. (1989). 'A Failure-Inducement Model of Research and Development Expenditure - Italian Evidence from the Early 1980s', *Journal of Economic Behavior and Organization,* Vol. 12, No. 2, pp. 159-180.

Arellano, M. and Bover, O. (1995). 'Another Look at the Instrumental Variable Estimation of Error-Components Models', *Journal of Econometrics,* Vol. 68, No. 1, pp. 29-52.

Arora, A., Fosfuri, A. and Gambardella, A. (2001) *Markets for Technology: The Economics of Innovation and Corporate Strategy,* MIT Press, Cambridge, MA.

Ballot, G., Fakhfakh, F. and Taymaz, E. (2001). 'Firms' Human Capital, R&D and Performance: A Study on French and Swedish Firms', *Labour Economics,* Vol. 8, No. 4, pp. 443-462.

Blundell, R. and Bond, S. (1998). 'Initial Conditions and Moment Restrictions in Dynamic Panel Data Models', *Journal of Econometrics,* Vol. 87, No. 1, pp. 115-143.

Blundell, R. and Bond, S. (2000). 'GMM Estimation with Persistent Panel Data: An Application to Production Functions', *Econometric Reviews,* Vol. 19, No. 3, pp. 321 - 340.

Bönte, W. (2003). 'R&D and Productivity: Internal vs. External R&D - Evidence from West German Manufacturing Industries', *Economics on Innovation and New Technology,* Vol. 12, No. 4, pp. 343-360.

Cassiman, B. and Veugelers, R. (2006). 'In Search of Complementarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition', *Management Science,* Vol. 52, No. 1, pp. 68-82.

Cohen, W. M. and Levinthal, D. A. (1989). 'Innovation and Learning: The Two Faces of R&D', *The Economic Journal,* Vol. 99, No. 397, pp. 569-596.

Cohen, W. M. and Levinthal, D. A. (1990). 'Absorptive Capacity: A New Perspective on Learning and Innovation', *Administrative Science Quarterly,* Vol. 35, No. 1, pp. 128-152.

Den Hertog, R. G. J. and Thurik, A. R. (1993). 'Determinants of Internal and External R&D: Some Dutch Evidence', *De Economist,* Vol. 141, No. 2, pp. 278-290.

Griffith, R., Redding, S. and van Reenen, J. (2003). 'R&D and Absorptive Capacity: Theory and Empirical Evidence', *Scandinavian Journal of Economics,* Vol. 105, No. 1, pp. 99-118.

Hadri, K. and Larsson, R. (2005). 'Testing for Stationarity in Heterogeneous Panel Data Where the Time Dimension is Finite', *Econometrics Journal,* Vol. 8, No. 1, pp. 55-69.

Hall, B. H., Mairesse, J. and Mohnen, P. (2009). 'Measuring the Returns to R&D'. *NBER Working Paper*, No. 15622, NBER.

Harrigan, J. (1997). 'Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model', *American Economic Review,* Vol. 87, No. 4, pp. 475-494.

Hempell, T. (2005). 'What's Spurious, What's Real? Measuring the Productivity Impacts of ICT at the Firm-Level', *Empirical Economics,* Vol. 30, No. 2, pp. 427-464.

Howells, J., James, A. and Malik, K. (2003). 'The Sourcing of Technological Knowledge: Distributed Innovation Processes and Dynamic Change', *R&D Management,* Vol. 33, No. 4, pp. 395-409.

Jankowski, J. E. (2001). 'Measurement and Growth of R&D Within the Service Economy', *Journal of Technology Transfer,* Vol. 26, No. 4, pp. 323-336.

Johansson, B. and Lööf, H. (2008). 'The Impact of Firm's R&D Strategy on Profit and Productivity'. *CESIS Electronic Working Paper*, No. 156, CESIS.

Lokshin, B., Belderbos, R. and Carree, M. (2008). 'The Productivity Effects of Internal and External R&D: Evidence from a Dynamic Panel Data Model', *Oxford Bulletin of Economics and Statistics,* Vol. 70, No. 3, pp. 399-413.

Mairesse, J. and Sassenou, M. (1991). 'R&D and Productivity: A Survey of Econometric Studies at the Firm Level'. *NBER Working Paper*, No. 3666, NBER.

O'Mahony, M. and Vecchi, M. (2009). 'R&D, Knowledge Spillovers and Company Productivity Performance', *Research Policy,* Vol. 38, No. 1, pp. 35-44.

Olley, G. S. and Pakes, A. (1996). 'The Dynamics of Productivity in the Telecommunications Equipment Industry', *Econometrica,* Vol. 64, No. 6, pp. 1263-1297.

Piga, C. A. and Vivarelli, M. (2004). 'Internal and External R&D: A Sample Selection Approach', *Oxford Bulletin of Economics and Statistics,* Vol. 66, No. 4, pp. 457-482.

Pisano, G. P. (1990). 'The R&D Boundaries of the Firm: An Empirical Analysis', *Administrative Science Quarterly,* Vol. 35, No. 1, pp. 153-176.

Rigby, D. and Zook, C. (2002). 'Open-Market Innovation', *Harvard Business Review,* Vol. 80, No. 10, pp. 80-89.

Roodman, D. (2009a). 'How to Do xtabond2: An Introduction to Difference and System GMM in Stata', *The Stata Journal,* Vol. 9, No. 1, pp. 86-136.

Roodman, D. (2009b). 'A Note on the Theme of Too Many Instruments', *Oxford Bulletin of Economics and Statistics,* Vol. 71, No. 1, pp. 135-158.

Santamaria, L., Nieto, M. J. and Barge-Gil, A. (2009). 'Beyond Formal R&D: Taking Advantage of Other Sources of Innovation in Low- and Medium-Technology Industries', *Research Policy,* Vol. 38, No. 3, pp. 507-517.

Schmiedeberg, C. (2008). 'Complementarities of Innovation Activities: An Empirical Analysis of the German Manufacturing Sector', *Research Policy,* Vol. 37, No. 9, pp. 1492-1503.

Van Biesebroeck, J. (2007). 'Robustness of Productivity Estimates', *Journal of Industrial Economics,* Vol. 55, No. 3, pp. 529-569.

Veugelers, R. (1997). 'Internal R&D Expenditures and External Technology Sourcing', *Research Policy,* Vol. 26, No. 3, pp. 303-315.

Veugelers, R. and Cassiman, B. (1999). 'Make and Buy in Innovation Strategies: Evidence from Belgian Manufacturing Firms', *Research Policy,* Vol. 28, No. 1, pp. 63-80.

Wieser, R. (2005). 'Research and Development Productivity and Spillovers: Empirical Evidence at the Firm Level', *Journal of Economic Surveys,* Vol. 19, No. 4, pp. 587-621.

Windmeijer, F. (2005). 'A Finite Sample Correction for the Variance of Linear Efficient Two-Step GMM Estimators', *Journal of Econometrics,* Vol. 126, No. 1, pp. 25-51.

TABLE 8

First step: Production function estimation. Dependent variable: log of value added

SNI 92		Employment		Capital		Obs.	No. of groups	AR(2)	AR(3)	Hans.	Diff. Hans.	No. of instr.
15-16	Food, bev. and tobacco	0.78***	(0.074)	0.16***	(0.057)	648	85	0.70	0.21	0.97	0.43	40[a]
17-19	Textiles, clothing and leather	0.90**	(0.377)	0.03	(0.131)	246	29	0.31	0.33	0.32	0.32	18 [a]
20-22	Wood, paper and publishing	1.01***	(0.089)	0.00	(0.054)	1040	122	0.43	0.41	0.46	0.84	40 [a]
23-24	Refined petrol.; Chemicals	0.73***	(0.145)	0.18*	(0.090)	737	105	0.00	0.91	0.35	0.52	38 [a,b]
25-26	Non-metallic mineral products	0.91***	(0.151)	0.16	(0.105)	903	117	0.75	0.82	0.48	0.32	40 [a]
27-28	Basic metals and metal products	1.05***	(0.077)	0.05	(0.065)	1027	125	0.61	0.39	0.91	0.68	58 [b]
29	Machinery and equipment	0.91***	(0.049)	0.06*	(0.035)	1675	224	0.02	0.54	0.24	0.31	138 [b]
30-31	Computers and electrical mach.	0.78***	(0.104)	0.13	(0.112)	433	79	0.08	0.27	0.66	0.64	26 [a,b]
32	Radio, television, and communication eq.	1.01***	(0.241)	0.05	(0.175)	195	33	0.02	0.78	0.45	0.79	22 [a,b]
33	Medical, precision, and optical instr.	0.62***	(0.183)	0.19**	(0.094)	660	103	0.53	0.18	0.90	0.35	40 [a]
34-35	Motor vehicles and other transport eq.	0.85***	(0.108)	0.11*	(0.066)	600	83	0.90	0.42	0.47	0.32	38 [a,b]
36-37	Other manuf; Recycling	1.00***	(0.188)	0.08	(0.110)	494	53	0.19	0.42	0.67	0.33	20 [a,b]

Robust standard errors in parentheses. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(2) and AR(3) are tests for autocorrelation of second and third order in residuals, respectively. Hans. is the Hansen test of overidentifying restriction. Diff. Hans. is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. [a] Instruments are collapsed. [b] The first lag used as instrument in the difference equation is the third lag. Time dummies included in all models. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used.