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Determinants of firm R&D:
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Patrik Gustavsson* and Andreas Poldahl**

Abstract

In this paper we analyse determinants of firm R&D using matched Swedish employer-employee data spanning the period 1990-1999. We explore if predictions from the model of creative destruction are supported by data. Using various measures of competition, results indicate that competition is likely to contract rather than expand firm R&D expenditures. In addition, firm R&D is positively correlated with its own export and to the R&D-intensity of other firms within the same concern, indicating the existence of knowledge spillovers.

Keywords: R&D, competition, firm size, spillovers
JEL classification codes: D4, L1, L6, O3

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1. Introduction

In 1997 Swedish firms spent 13.8 % of firms' value added on research and development (R&D) or in absolute terms, 40 billion Swedish crowns (SEK). As R&D is a major factor driving economic growth, changes in R&D spending may be associated to the evolution of technology. However, a brief look at data reveals that the R&D intensity differs between industries and firms. It is therefore well motivated to think about how different factors and economic conditions affect R&D.

The vast majority of empirical studies on this topic utilize industry level data or limited surveys; see e.g. Stoneman (1995) and Aghion & Howitt (1999). As detailed firm-level data have become available, the possibility of examining the factors affecting decisions behind firm-level R&D has become feasible. Our contribution here is at least twofold. First, R&D is an activity associated to the firm-level. By using a highly detailed pooled employer-employee dataset covering *all* manufacturing firms with at least 50 employees, our results relate directly to the firm without any severe sample selection bias. Second, we pay special attention to the impact of competition on R&D.

Since the breakthrough of endogenous growth theory in the late 1980's and early 1990's great advances in modeling endogenous growth have emerged, see e.g., Aghion and Howitt, (1992, 1999), Young (1995) and Jones (1995). However, as Aghion and Howitt (1999) note

> "less progress has been made at the empirical level."

Their statement highlights the need for detailed empirical analysis on this topic. Our analysis is based on the basic Aghion and Howitt (1992) model but no formal test of the theory of creative destruction is performed. Instead we find support in Aghion and Howitt's (1999) statement,

> "Any empirical challenge to Schumpetarian models should go well beyond existing work,"

indicating the complexity of a formal test of the Schumpeterian theory.

The impact of competition on R&D is of particular interest from both a theoretical and policymaking point of view. As is well known, Schumpeter (1934) predicted a negative relation between product market competition and R&D, a statement that has thereafter been challenged by models predicting the opposite relation. Aghion & Howitt (1999) show how various changes in the model set-up may reverse the predicted negative impact of competition on R&D and growth.

The empirical evidence regarding the impact of competition on R&D is likewise mixed. An early study on this topic is Horowitz (1962) who found competition to contract R&D while Scherer (1967) found a non-linear relation between competition and R&D. Studying the relation between R&D and productivity growth, Nickell (1996) and Blundell *et al.*, (1995) found product market competition to actually stimulate R&D expenditures.[1] This mixed evidence motivates the need for new studies on this topic. The use of firm-level data allows us to efficiently control for both firm- and industry level effects. We use a number of different measures of product-market competition where each measure reflects competition from its own perspective. This approach may deepen our understanding of how competition is related to innovative activity.

Our results indicate that competition is more likely to contract than expand firms' R&D, thus supporting Schumpeter's prediction.

Apart from competition there are a number of other factors that affect R&D. The perhaps best documented variable is the connection between firm-size and R&D spending. Schumpeter (1934) argued for a large-firm advantage in R&D, a proposition that has been tested in an array of papers, see Stoneman (1995) for a survey. Explanations for a large-firm advantage in R&D are; capital market imperfections, increasing returns in R&D itself, the possibility for large firms to spread R&D cost on long production runs and complementarities between R&D and other activities. Some studies have found R&D to increase more than proportionally with firm size (see e.g. Meisel and Lin, 1983), while the broad mass finds proportionality (see e.g. Sherer (1984b) and Baldwin and Scott (1987)). Acs and Audretsch (1990, 1991b) find that small firms tend to account for a disproportionately large share of innovations. We do not find any strong support for a large firm advantage in R&D. Rather, if anything, our results indicate that small firms perform a disproportionate large share of R&D.

A complicated issue is the impact of technological opportunity and appropriability conditions on R&D and how to empirically operationalise these concepts. Technological opportunity deals with the possibility of converting research resources into new enhanced techniques of production. Appropriability deals with the possibility for an inventor to exclude other firms from exploiting an innovation which is usually linked to the patent system. Geroski (1991b) argues that in the early stage of the product cycle, technological opportunity is high which stimulates entry. Further, Aghion and Howitt (1999) show that a positive correlation between the entry and

[1] For a survey, see Cohen (1995) and references therein.

exit rates of firms and productivity growth can be established. We argue that both entry and exit may be high when technological opportunity and product development are high and apply the firm turnover rate as a proxy for the technological opportunity in an industry. Due to the exceptional difficulties of making these concepts operational, some researchers have argued for a fixed effect treatment of these concepts, see e.g. Geroski (1990). Our results give some support to the model prediction that technological opportunity, reflected by the firm turnover rate, is positively related to firm R&D.

The contribution of this paper is not only in sharpening our understanding of competition on R&D, it also provides evidence as to whether Schumpetarian growth models are supported by firm-level data.

The paper is organised as follows: section 2 presents the theoretical model, in section 3 data, variables and estimation issues are discussed, section 4 contains the econometric results and section 5 concludes.

2. The model

To the best of our knowledge there is no explicit theoretical model comprehensive and rich enough to embody all of the effects/variables which we believe to be relevant in determining R&D and which have been used to that purpose in the empirical literature. However, the Schumpetarian model is flexible and has been extended in various directions. We take the basic set-up of Aghion and Howitt (1992) as our starting point. As new variables are appended we relate the results with predictions from the corresponding theoretical extension. No attempts are made to retrieve parameters in the theoretical model.

R&D is treated as a firm-level activity and we put the model into a disaggregated set-up. Firms are treated as independent of each other and within each firm we a have a profit maximising final good-, intermediate good- and R&D-sector. At first glance it may seem awkward to treat various sectors within a firm as separate units, on the other hand, each unit is driven by profit motives and the gain from an innovation is kept within the innovating firm as the innovation makes the final good more competitive. We argue that this is at the heart of firms' R&D and this causality is captured in our specification. As the analysis proceeds we allow for interactions between firms within the same concern and trade to affect firm R&D.[2] Finally, to allow for a richer analysis of competition and demand we specify final good demand to be of the Spence-Dixit-Stiglitz (S-D-S) form.[3] Since we build on a well-known model, the description is kept brief, for details see Aghion and Howitt (1992).

Assumptions

Assume J industries $j = 1,\ldots,J$. In each industry we have F_j firms, each firm producing a differentiated product using V factors of production $v = 1,\ldots,V$ using a generalised Cobb-Douglas technology. All final good input factors are mobile between firms and industries except human capital, which is assumed to be firm specific.[4] The final good market is characterised by monopolistic competition while perfect competition is assumed on the factor market.

The R&D unit uses firm-specific human capital as the only input in the production of new designs whose state of technology or 'generation' is indexed by (i). The firm-specific human capital ($H_{f,j}$) is divided between R&D, denoted with subscript R ($H_{R,f,j}$), and intermediate good production indexed I ($H_{I,f,j}$). When a new design arrives the intermediate good based on previous technology becomes obsolete. The intermediate good unit has a perpetual monopoly and sells the intermediate good $V_{x,f,j}$ to the firm's final good unit, thereby recovering costs and keeping the benefit of the innovation within the firm. An innovation by firm f increases productivity in the final good production by a factor of $g^{a_{x,f,j}} > 1$, where γ measures the height of innovations and $a_{x,f,j}$ is the input coefficient of intermediates in final good production. Solving the model, the steady state level of human capital allocated to R&D by a firm is;[5]

$$H_{R,f,j}^{SS} = \frac{\Psi_{f,j}\; g^{a_{x,f,j}} H_{f,j} - r/l}{1 + \Psi_{f,j}\; g^{a_{x,f,j}}} \quad ;where\;\; \Psi_{f,j} = \frac{s_j(1 - a_{x,f,j}) + a_{x,f,j}}{a_{x,f,j}(s_j - 1)} > 0 \qquad (1)$$

where: $H_{R,f,j}^{SS}$ is the steady state level of human capital allocated to R&D by firm f in industry j, $H_{f,j}^{SS}$ is firm f's human capital stock, α_x and σ_j measures

[2] By a concern we mean a group of two firms or more, connected by ownership. The members of a concern are defined in each firm's book accounts and registered by Statistics Sweden. Usually, each concern has a concern mother.

[3] Spence (1976), and Dixit-Stiglitz (1977).

[4] The theory of firm-specific human capital is a core part of Labour economics. See Farber (1999). "Mobility and Stability: The Dynamics of Job Change in Labor Markets," *Handbook of Labor Economics*. Vol 3b.

[5] Time indices are suppressed unless necessary for the context.

the input intensity of the skilled intensive intermediate good and the elasticity of demand respectively, λ measures the R&D efficiency, γ is the height of innovations and r is the interest rate.[6]

3. Data, the empirical model and estimation issues

3.1 Data

Data are obtained from Statistics Sweden, Financial Statistics (*FS*) and Regional Labour Statistics (*RAMS*). These datasets contain information on all manufacturing firms with at least 50 employees, spanning the period 1990 to 1999. *RAMS* contain mainly information on employees' education and wages while *FS* contain information about firms' input and output.

The dependent variable in the analysis is firms' *research and development* (*R&D*) expenditures. Data on the R&D variable stem from the Financial Statistics (*FS*) and cover all firms with at least one employee active in R&D activities at a minimum of 50% of full time. The *FS* is retrieved annually and is compulsory for firms to reply. Respondents are asked to give an exact figure for R&D expenditure or to answer in an interval scale.[7]

Studying data we note some interesting findings. In Table 1 we can see that there is a strong concentration of total R&D to a small number of firms. The top ten firms' represent roughly 60-70 percent of total R&D. If the R&D propensity differs systematically between high and low R&D-spending firms, R&D weighted regressions may alter results. Moreover, the importance of foreign-owned firms on the Swedish labour market has increased dramatically over time. During the period 1990-1999 foreign-owned firms' employment share almost doubled (increasing from 18 to 32 percent). Based on this observation we might ask if the R&D propensity differs between Swedish and foreign owned firms. If foreign-owned firms

[6] The elasticity of substitution (σ) is larger than unity.
[7] An alternative to the FS R&D data is the bi-annually collected Research Statistics (*RS*), based on all firms within the FS with at least 200 employees and on a sample of firms with 50 – 200 employees, given that theses firms report R&D expenditures of at least 200 000 SEK to the *FS*. In context of statistical reliability, the bi-annually collected "Research Statistics" is of higher quality but has less coverage. The *RS* and *FS* data generate basically the same results but the RS reduces the sample size with more than 50% and we therefore focus on results from the FS.

tend to keep the innovative activity in the home country the globalisation of the Swedish industry may have a contracting impact on total R&D.

Finally, Table 2 reveals tremendous variation in the R&D intensity between industries. The most R&D intensive industry (communication) spent 50 percent of valued added on R&D in 1999 while the corresponding number for "publishers and printers" was 0.2 percent. Obviously, the importance and impact of a policy intended to affect firm R&D may be very different in different industries.

Table 1: Summary statistics

Year	No of firms	Number of foreign firms (employment share)	Number of public firms (employment share)	R&D share performed by the top ten firms
1990	1960	339 (18.6%)	75 (5.9%)	60%
1991	1884	360 (20.9%)	83 (8.1%)	62%
1992	1730	359 (21.4%)	90 (9.4%)	55%
1993	1565	316 (20.0%)	58 (5.9%)	58%
1994	1578	335 (19.9%)	63 (12.2%)	79%
1995	1657	400 (23.6%)	43 (7.8%)	65%
1996	1731	406 (23.9%)	52 (8.6%)	56%
1997	1729	422 (25.2%)	63 (8.0%)	66%
1998	1801	471 (27.6%)	60 (7.4%)	67%
1999	1820	487 (32.0%)	59 (7.4%)	72%
	Tot 17 455 and 3 275 unique firms	Tot 3895	Tot 646	

Table 2: R&D intensities by industry, 1999.

SNI 92	Industry	R&D intensity	SNI 92	Industry	R&D intensity
15	Food	1.5	26	Non mineral products	4.3
16	Tobacco	5.2	27	Basic metals	4.5
17	Textiles	3.7	28	Metal products	2
18	Clothing	0.2	29	Machinery and equipment	13.6
19	Leather	1.4	30	Computer	27.4
20	Wood and furniture	0.5	31	Electrical machinery	9.9
21	Pulp and paper	3.4	32	Communication	51.2
22	Publisher and printers	0.2	33	Medical, precision and ..	31.2
23	Refineries	4.7	34	Motor vehicles	24.3
24	Chemicals	39	35	Other transport equipment	10.9
25	Rubber and plastic	4.1	36	Other manufacturing	3.4
Total No of observations, (firms with R&D>0) 2258					

Note: SNI 92 correspond to the ISIC rev(3) standard of classification.

3.2 Variables and the empirical model

We base the analysis on the variables in equation (1). Due to severe difficulties in estimating the derived highly non-linear functional form equation (1) and in order to keep things tractable, the econometric analysis is performed on a general functional form. As additional hypotheses are discussed the corresponding variables are appended. No attempts are made to retrieve all parameters in the theoretical model.

As we want to pay special attention to the impact of competition on R&D and due to the fact that competition is a complex concept to define and measure, we apply three different measures of competition. Using these measures of competition we evaluate the impact of competition from different perspectives thus allowing us to evaluate the robustness of the relation. As measures of product market competition we apply the Herfindahl index *(H)*, market concentration *(C3)*, and firm's profit ratio, *(p)*. *C3* is measured as the market (share of total sales) in an industry held by the three largest firms.

There are of course variables other than competition that affect firm R&D. The perhaps most obvious and well-studied candidate is firm size. Decades of empirical research on the relationship between firm size and R&D have established a number of empirical patterns. Although some of these patterns have been subject to controversy, economists have arrived at a consensus view of an elasticity of R&D with respect to firm size close to unity. However, the relationship may be non-linear. We use firm's turnover as a proxy for firm size. To allow for possible non-linearity of the firm size component a spline transformation is applied. As the interesting question here is if proportionality can be rejected or not, focus is set on if the estimated elasticity of R&D with respect to firm size deviates from unity.

Firms' incentive to perform R&D is closely related to their knowledge about the risk and outcome of a project. One channel of information that might help the firm to carry out an R&D project is technology spillovers. Griliches (1992) points at substantive spillovers associated with trade. Coe and Helpman (1995) apply R&D weighted import to capture international technology spillovers. Their results confirm that imports might work as a channel for foreign technology spillovers. Keller has in an array of papers (see e.g. Keller 1997, 2000, 2002a, 2002b) studied both national and international technology spillovers. In short, his results indicate robust evidence on the existence of technology spillovers.

We analyse technology spillovers using two variables. First, to capture cross-country spillovers we apply firm's export-ratio. In line with e.g. Cohen and Levinthal (1989), we argue that trade may open channels for technology transfers thus increasing firms' technology absorption and stimulating R&D. Secondly, we argue that the transmission of information meets less resistance among firms within the same concern compared to firms outside the concern. Therefore, a firm active in an R&D intensive concern is *a priori* expected to have an edge in R&D.[8] To capture the technological environment within the concern we apply the concern R&D intensity (excluding the firms own contribution to the concern).

Human capital and its relevance for the innovative process are highlighted in the endogenous growth theory (see e.g. Grossman and Helpman (1991)).[9] A delicate econometric issue is the direction of causality; does firms' R&D depend on their human capital abundance or vice versa? We measure a firm's human capital using the wage share devoted to skilled labour (labour with at least post secondary education) and tackle possible endogenity by way of an instrumental variable approach.[10]

Firm R&D does not only depend on firm-specific characteristics, industry characteristics have also been shown to affect firm R&D. In the early literature, researchers have come to distinguish between three classes of explanatory variables that may capture inter-industry variation in R&D, namely appropriability conditions, opportunity conditions and product demand. Many researchers have realised the importance of these components on firm incentives to invest in R&D while still lacking a clear and precise understanding of how to conceptualise/measure these concepts. Technological opportunity is about the possibility of converting the benefit of an innovation to a new enhanced product or production process. Geroski (1991b) argues that industries in the early phase of the product cycle may be characterised by high rates of innovation, firm turnover and a high level of technological opportunity which stimulates R&D. More recently Aghion and Howitt (1999) demonstrate how a positive correlation between productivity growth and entry and exit of firms can be established. A reasonable way to describe technological opportunity may therefore be the firm turnover rate (*Fto3*), measured as the share of firm entry and exit within a given industry. Our prior is that a high firm turnover rate is positively associated with firm R&D.

In the empirical literature on the determinants of firm R&D effort the capital intensity of the firm has been largely ignored. This is surprising since technological innovations are typically embodied in new machinery

8 We might expect the opposite if firms within a concern tend to concentrate the R&D activity to one firm.

9 An different perspective is taken by Teece (1986, 1987) who applies a transaction cost framework in linking human capital to firm's possibility to become a successful innovator.

10 In Sweden, approximately 21% percent of workers with post-secondary education within the manufacturing industry are involved in R&D related work, (Statistics Sweden, (2001)).

(embodied technological change).[11] Further, DeLong and Summers (1991) argue that countries with high capital investment rates tend to be those with high productivity growth. Aghion and Howitt (1999) extend their basic model and demonstrate how the introduction of capital in the intermediate production can establish a positive correlation between innovation and capital intensity. We argue that observed between-industry differences in capital intensity to some extent reflect the production of different goods while within-firm variation is more likely to tell us something about a firm's choice of production technology in the production of a given product (see Table 5). To sum up, it is well motivated to include capital in the analysis of firm R&D and to expect a positive correlation between firm capital intensity and R&D.

4. Results and estimation issues

In line with Acs and Audretsch (1990, 1991b) we find the average R&D elasticity with respect to firm size to be less than unity with estimates ranging from 0.90 to 0.96. As shown in Table 1, a few firms account for a large share of total R&D expenditures. To control for the skewed distribution of R&D expenditures, we perform a R&D weighted regression. In a weighted regression, the estimated R&D elasticity, maybe surprisingly, drops by approximately 20%. This drop indicates that the R&D elasticity among the largest R&D firms is below the average.

To get even one step further, we investigate differences in R&D propensity among firms of different size. To be precise, we apply a spline and divide the sample into small and large firms. Contrary to what may be expected from the weighted regression, the elasticity of large firms turns out to be larger than for small firms. In fact, the estimated large firm elasticity slightly exceeds unity while the elasticity of small firms falls in the interval 0.5-0.8.[12] The results from these models can all be true simultaneously only if the R&D propensity among firms of similar size differs. More precisely, these results can coexist if, for a given firm size, the R&D elasticity decreases as R&D spending increases. With such heterogeneity large firms' R&D-elasticity may on average be larger than for smaller firms while for the very few number of top R&D spending firms the R&D elasticity may

[11] See e.g. Stoneman (1983).

[12] The Fixed effect estimator returns a very low estimate of the R&D to firm size elasticity, to some extent this may be an artefact of a relatively low time series variation in the firm size variable.

Table 3: Regression results.
Dependent variable: natural log of firms' R&D expenditures

	Mod 1	**Mod 2**	**Mod 3**	**Mod 4**	**Mod 5**	**Mod 6**
Variables	**OLS** **[basic model]**	**2SLS**[E]	**2SLS**[E,F] **[R&D weighted]**	**FGLS**[B,E]	**FGLS**[B,E]	**FE**[C,E]
Ln(sales)	0.90*** !	0.96***	0.77***	-	-	-
	(0.000)	(0.000)	(0.000)	-	-	-
1. ln(sales)[A] *[small]*	-	-	-	0.47*** !!!	0.81*** !!!	0.29** !!!
	-	-	-	(0.000)	(0.000)	(0.004)
2. ln(sales) [large]	-	-	-	1.05*** !	1.03*** !!	0.63*** !!!
	-	-	-	(0.000)	(0.000)	(0.000)
H	0.0001**	0.0001**	-0.00004	-0.0001**	$3.23 \cdot 10^{-6}$	-0.00002
	(0.007)	(0.003)	(0.498)	(0.012)	(0.501)	(0.129)
Fto3	0.01**	0.01**	0.012	-0.002	-0.001***	0.001
	(0.026)	(0.023)	(0.103)	(0.188)	(0.000)	(0.721)
Ln(wH-ratio)	1.10***	1.13***	1.34***	0.84***	0.71***	0.25*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.057)
Ln(k)	-	-0.23***	-0.19*	0.09**	0.03***	0.02
	-	(0.000)	(0.061)	(0.002)	(0.000)	(0.495)
Ln(Ex)	-	0.27***	0.54**	0.13***	0.17***	0.22***
	-	(0.000)	(0.024)	(0.000)	(0.000)	(0.000)
Ln(C-R&D)	-	-	-	0.19***	-	-
	-	-	-	(0.000)	-	-
Government Dummy	-0.09 (0.673)	-0.01 (0.947)	-0.004 (0.984)	-0.02 (0.813)	0.02 (0.410)	-0.01 (0.919)
Foreign Dummy	0.11 (0.187)	-0.007 (0.934)	-0.70** (0.019)	0.26 (0.283)	0.02** (0.004)	-0.01 (0.868)
Ind dummies	No	No	No	Yes	Yes	No
Time dummies[D]	Yes	Yes	Yes	Yes	Yes	Yes
Firm effects	No	No	No	No	No	Yes
R^2 adjusted	0.58	0.63	0.72	-	-	-
- Within	-	-	-	-	-	0.04
- Between	-	-	-	-	-	0.57
- Overall	-	-	-	-	-	0.55
Obs	8384	6260	6260	1040	6052	6260

Notes: p-values within brackets. In model 1 through 3 the White estimator is used. ***, **, * indicate significance at the 1, 5 and 10 percent level respectively. !!!, !!, ! indicate the parameter is significantly different from unity at the 1, 5 and 10 percent level respectively (only applied on the *ln*(sales) variable).

[A] Intervals are constructed such that they contain approximately the same number of observations.

[B] We allow for a first order panel specific autocorrelation and heteroscedasticity in the error term.

[C] The Breusch-Pagan, (p-value=0.000) and Hausman test (p-value=0.000) rejects validity of the random effect model.

[D] Time dummies are always significant at the 10 percent level except in the third model.

[E] One period lag of *ln*(Ex) and *ln*(wH-ratio) is used as instrument for *ln*(Ex) and *ln*(wH-ratio). Instruments for *ln*(C1-R&D) are *ln*(k), *ln*(sales) and *ln*(wH-ratio) and *ln*(Ex) where all instruments are filtered with the concern-filter *"C1"*.

[F] Weights applied are firm's relative R&D expenditure.

be significantly lower. As a final word, we note that our results do not indicate any convincing evidence for a large-firm advantage in R&D.

In our analysis of competition we first apply the time and industry specific Herfindahl index as our measure of product market competition. The Herfindahl index are bounded in the interval 0-10 000 where a value of 10 000 indicate a monopoly. In regressions without control for fixed industry effects (Table 3, model 1-3) the Herfindahl index is positive and significant in two out of three models indicating that competition mitigates R&D. However, given control for individual heterogeneity or fixed industry effects (Table 3, model 4-6) the Herfindahl index becomes insignificant or even negatively significant. One should however notice that the negative significant estimate is based on a limited sample containing only firms belonging to any of the 80 largest concerns. As the inclusion/exclusion of industry dummies seems to be important for the results on competition we perform a sensitivity analysis, presented in Table 4. The sensitivity analysis is based on the specification in model five where we apply three different proxies for competition (the Herfindahl index, market concentration and firms' profit ratio) and estimate the model with and without industry dummies.

The sensitivity analysis reveals that in all specifications without industry dummies we find competition to be a contracting force on firm R&D. However, if we include industry dummies, the picture becomes less clear. First, for firm profit ratio the same pattern remains. Second, the Herfindahl index loses its significance and *C3* reverses sign, now indicating that competition boosts R&D.

Table 4: Sensitivity analysis, different measures of competition

Variable	*Industry dummies*	
	Yes	no
H	$3.23 \cdot 10^{-6}$ (0.501)	0.0001^{***} (0.000)
C3	-0.001^{***} (0.000)	0.004^{***} (0.000)
p	0.12^{***} (0.000)	0.11^{***} (0.000)

Note: The econometric specification corresponds to model 5.

To understand the mechanism driving these results we make a closer inspection of the variation in the data. Table 5 reveals that the between-industry standard deviation is roughly three times larger compared to the time series variation for both the *C3* and the Herfindahl index. The simple message is that there is relatively small variation in the degree of competition in the time dimension while it may vary in the cross sectional dimension. This is not surprising since competition is naturally thought of as an industry characteristic. Davies and Geroski (1997) point out that even if individual firm's market share varies over time the industry concentration ratio might be rather stable. Hence, when analysing competition there is not much information in the time series dimension. Taking this into account our main impression is that R&D investments tend to confer to firms with some form of market power and that competition tends to be an industry attribute.

Table 5: Variance decomposition

Variable	Overall standard deviation	Within standard deviation	Between standard deviation
R&D	245 896	149768	146287
Sales	1 682 752	662073	1194549
K/L	374.5	158	349.2
WH-ratio	13.8	3.5	14.1
Ex	31.0	10.0	28.6
C-R&D	4.8	1.6	4.4
Profit-ratio (p)	0.6	0.5	0.4
Fto3 (ind level)	15.5	14.2	7.0
H (ind level)	0.0008	0.0002	0.0007
C3 (ind level)	24.9	7.7	24.2

For technological opportunity a similar pattern as for competition is detected. Given no control for industry effects (Table 3, model 1-3) the estimated coefficient on the firm turnover rate (*Fto3*) is positive and significant. One interpretation of this is that firms within industries with high firm turnover rates (industries in the early stage of product life cycle) will set off more resources directed to R&D activities. However, if we control for fixed industry effects, the estimated sign is insignificant or reversed. This change of results when including industry effects may indicate that within a given industry, increasing entry and exit rates might signal uncertainty about future market shares making firms unwilling to undertake uncertain R&D investments. However, in the cross-industry dimension *Fto3* is more likely to capture the relative maturity and level of technological opportunity in an industry. In quantitative terms we find the partial effect (where significant) of a one-percentage unit increase in the firm turnover rate to imply an expected change of -0.1 to 1.2 percent in R&D expenditures.

The incentives to perform R&D are affected by the information set held by the firm. One channel of information is technology spillovers. Spillovers may be thought of as connected to the flow of goods or as "being in the air" i.e. as intangible. There is also a spatial dimension where we may distinguish between local and international spillovers. We analyse local technology spillovers by studying R&D interdependence among firms within the same concern. To be precise, we analyse how being part of an R&D-intensive concern affects the individual firm's R&D expenditures. The concern interaction variable captures the R&D intensity of all firms within the same concern, excluding the firms' own contribution to the concern and we label this variable, *C-R&D*. Including such a spillover variable however, incurs the problem of endogenity. This kind of interdependence is a part of spatial econometrics and in line with this literature we tackle the endogenity by way of IV-techniques where the instruments have been transformed by the same filter as R&D itself (when transformed to *C-R&D*).[13] One drawback is that our concern variable only covers firms that belong to one of the 80 largest concerns and information is available only until 1997. Hence, when appending this variable the sample is reduced from approximately 6000 to 1000 observations. In model 4 we append the concern-interaction variable and reveal a positive and significant effect of this interaction on firm R&D. Results suggest that an increase in the concern R&D-intensity by one percent implies an increase in firm R&D expenditures of roughly 0.2%.

Levels and trends in exports of "high" and "medium" technology products have been widely used as an indicator of innovative performance (see e.g. Patel and Pavitt (1987)). The expected effect of export is to promote R&D. However, we may suspect a bias among exporting firms toward high productivity firms, a problem that is conveniently tackled by IV-techniques. In the estimations, the export intensity variable is positive and significant in all specifications and the inclusion/exclusion of industry dummies do not upset the result. Regressions point at an estimated elasticity of R&D with respect to export in the interval of 0.13-0.54.

We may therefore conclude that our results on spillovers point at both exports and the concern R&D-intensity to give substantial feedback to firm R&D.

Following Aghion and Howitt (1999) who show how the introduction of physical capital can establish a positive correlation between innovation and capital intensity, we introduce firm's capital intensity to investigate if this proposition is supported by data.

Given that industry dummies are excluded, the econometric analysis returns a negative and statistically significant coefficient on firm capital-intensity $ln(k)$. Including industry dummies (or differencing out unobserved

[13] For an introduction of spatial econometrics, see Anselin (1988).

heterogeneity using the FE estimator) reverses the estimated sign. As we control for industry/firm specific effects in regression model 4-6 these results indicate that firm R&D is positively related to its capital intensity, supporting Aghion and Howitt's (1999) hypothesis.

Due to imperfect data we do not have information on the number of employees in each firm occupied with R&D. Our information is restricted to the firms' wage sum divided by skilled and unskilled workers. The model predicts that in steady state a constant share of firm human capital is allocated to R&D (a unit elasticity). As a determinant for firm R&D and as an indirect test of the model, we therefore apply firms wage-share to skilled labour, *ln*(*wH-ratio*).[14] Analogous, in steady state, the model predict this share to be constant.

According to Statistics Sweden, approximately 21% of the total wage-sum to skilled labour is allocated to workers involved in R&D related activities (2001). We approach endogenity using instrumental variable techniques. Result from the FGLS estimator points at elasticity of R&D with respect to firm's wage-share to skilled labour in the range 0.71-0.84. Results are significant and insensitive to choice of IV-matrix indicating a robust relation between human capital and firm R&D.

As the cost of performing R&D is substantial, the possibility to collect risk capital is crucial in financing risky R&D projects. One may argue that public firms face fewer obstacles than private ones in collecting such capital. In our data, the "public owned" dummy variable is insignificant indicating no differences in R&D propensity between public and private firms.

Studies of multinational firms show that most of their innovative activity is performed in the home country (Cantwell (1992)). This suggests that multinational firms tend to keep technological activities at home. However, our results do not indicate that foreign firms invest less in R&D than domestic ones and the estimated (mostly insignificant) differences are small enough to be negligible.

5. Conclusions

As we base our analysis on the Aghion & Howitt (1992, 1999) model our aim is to compare our results with predictions of the theoretical model. The basic (1992) model predicts a unit elasticity of R&D with respect to firm

[14] Wageshare to labour with at least post secondary education.

size. Analysis of data reveals an estimated elasticity close to, but usually smaller than, unity. To be precise, the average- and small firm elasticity is significantly below unity while large firms' R&D elasticity slightly exceeds unity. Moreover, the distribution of firm R&D spending is skewed; the top-ten R&D spending firms account for roughly 60% of total R&D expenditures. To investigate how the skewed distribution affects results we performed a weighted regression. Perhaps surprisingly, weighted estimation decreases the estimated average elasticity by approximately 20%. Jointly these results suggest that, for a given firm size, the R&D elasticity decreases as R&D spending increases.

Competition is naturally thought of as an industry characteristic. In line with this proposition we find that our industry specific measures of competition show greater variation in the cross-industry dimension compared to the time series variation. As it turns out, this difference has an effect on the estimated impact of competition on R&D.

Given no control for industry specific effects, we find competition to contract firms' R&D spending. However, when we control for industry specific effects, the significance of our competition measures tend to vanish and in some cases even reverses. Taking all results into account our impression however is that competition is more likely to contract than expand firm R&D expenditures. Hence, our results do not reject predictions of the basic Aghion and Howitt (1992) model.

For technological opportunity, a similar pattern as that for competition is revealed. Given that no industry dummies are included, the industry firm turnover rate *Fto3*, is found to boost firms' R&D. However, the inclusion of industry dummies tends to reverse this result. We argue that in the cross-industry dimension, a high firm-turnover rate is positively correlated with technological opportunity. However, for a given industry and therefore a given level of technological opportunity, an increased firm turnover rate may indicate an increased risk, which *ceteris paribus*, if anything, tends to contract firm R&D.

Technology spillovers may provide firms with information, reducing the uncertainty associated with R&D projects. We capture international technology spillovers by using firms' exports. Local spillovers are analysed by studying how a firm within a concern is affected by the R&D-intensity of other firms within the same concern.

Results on spillovers verify that both export and the concern R&D intensity return substantial feedback on firms' R&D. Hence, in line with e.g. Keller (2000, 2002b) and Cohen and Levinthal (1989) our results point at technology spillovers as an important channel for innovative activity.

As is well known, human capital is an important factor in R&D. In support of the model of creative destruction we find robust evidence for firm human capital to be a significant determinant for R&D spending. Results point at an elasticity of R&D with respect to firm's wage-share to skilled labour in the range 0.71-0.84 and the results are robust with respect to choice of instrumental variable matrix.

Aghion and Howitt (1999) show how a positive correlation between innovation and capital intensity can be established. To find out whether this proposition is supported by data we introduce firm capital intensity as a regressor.

Given no control for industry-specific effects, the partial correlation between firm R&D capital intensity is negative while including industry dummies or differencing out fixed effects, this relation is reversed. This change may simply reflect that in the cross-section we are comparing the production of different goods while in the time dimension we are more likely to compare different production techniques in the production of the same product. We argue that for a given firm, as the capital intensity increases, so does it's technological level and as a consequence it's R&D, supporting Aghion and Howitts' (1999) proposition.

Finally, ownership whether public/private or foreign/domestic only marginally affects firm R&D.

As a final word we conclude that the basic growth model of Aghion and Howitt (1992) and their (1999) extensions, tested here, stands up rather well when confronted with micro data.

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Appendix

Table A1: Variable definitions

Variable	***Description***
R&D	Total R&D expenditures[15], 1990 constant prices. Source: Statistics Sweden/Research Statistics.
Sales	*Total turnover (including total sales revenue and interest rate receipts).* *Source: Statistics Sweden/Financial Statistics.*
Fto3	Firm turnover rate measured as the share of entrants and exits to the total number of firms at the 3-digit level. Source: Statistics Sweden/Financial Statistics.
C3	Concentration ratio. The three largest firms share of total industry output at the SNI-92 3 digit level. Source: Statistics Sweden/Financial Statistics.
C-R&D	The concern intensity measured as total R&D expenditures to the total sales at the concern level (including all other active firms').
H	Herfindahl index, calculatet at the 3 digit level. Statistics Sweden/Financial Statistics.
p	Profit-ratio, (net profit/turnover). Source: Statistics Sweden/Financial Statistics.
K/L	Capital stock per employee.[16] Source: Statistics Sweden/Financial Statistics.
wH-ratio[17]	Share of total wagesum to employees with post secondary education. Source: Statistics Sweden/Regional Labour Statistics.
WH	Total wagesum to employees with post secondary education. Source: Statistics Sweden/Regional Labour Statistics.
Ex	Value of total exports in percent of sales. Source: Statistics Sweden/Financial Statistics.
Government dummy	Dummy for public owned firms. Source: Statistics Sweden/Financial Statistics.
Foreign dummy	Dummy for foreign owned firms. Source: Statistics Sweden/Financial Statistics.

Note: The consumer price indexis used to convert sales and profits into constant prices and the producer price deflator applies to R&D[18] expenditures. The capital stocks: book value of capital/physical capital and gross net investments has been deflated by price index of buildings and machinery.

[15] R&D is an activity, which takes place on a systematic basic to increase the body of knowledge, including the knowledge of people, culture and society as well as the application of this knowledge to new areas and to develop or improve products, systems and methods (definition of Statistics of Sweden).

[16] The physical capital stock is constructed by cumulating investments to the book value, which is applied as start value. We apply a depreciation rate of machinery and inventory of 11 % and 3% annually.

[17] The share of high skilled labour (with post secondary education) in R&D related activities equals 21% in 1999.

[18] The choice of deflator is not clear cut, since R&D expenditures to a large extent is compensation to researchers we choose the PPI at the 1 digit level.

Variable construction

Below we present additional description of selected variables.

1. Firm turnover rate, $Fto3_{mt} = \frac{(number\ of\ entry + number\ of\ exit)_{mt}}{total\ number\ of\ firms_{mt}}$

The firm turnover rate is defined on a 3-digit code level of SNI 92.
i = firms, t = time index, m = industry according to 3 digit SNI 92.

2. Herfindahl index, $H_{mt} = \left\{ \sum_{i=1}^{N} s_{it}^2 \right\}$, where $s_{it} = \frac{sales_{it}}{\sum_{i=1}^{N} sales_{it}}$

3. Concentration ratio, $C3_{mt} = \frac{\sum_{i=1}^{3} max(sales_{it})}{\sum_{i=1}^{N} sales_{it}}$

4. The concern R&D intensity, $C - R\&D_{it} = \frac{\sum_{j=1}^{N} R\&D_{jt}}{\sum_{j=1}^{N} sales_{jt}},\ j \neq i$

Table A 1: Correlation matrix

	K/L	*wH -ratio*	*p*	*R&D*	*Ex*	*Sales*	*C-R&D*	*Fto*	*H*
K/L	1.00								
wH-ratio	0.07	1.00							
p	-0.45	-0.12	1.00						
R&D	-0.017	0.24	0.01	1.00					
Ex	0.08	0.24	0.03	0.16	1.00				
Sales	0.05	0.18	0.02	0.78	0.21	1.00			
C-R&D	-0.09	0.39	0.00	0.28	0.10	0.17	1.00		
Fto	-0.07	0.06	0.03	0.09	-0.04	0.03	0.18	1.00	
H	0.04	-0.18	-0.04	-0.14	-0.20	-0.16	-0.28	-0.08	1.00
C3	-0.08	0.23	0.06	0.20	0.10	0.20	0.33	0.13	-0.86