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Is There Really an Inverted U-shaped Relation Between Competition and R&D?

By

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Abstract

We test whether predictions of the Aghion and Howitt (2004) model are supported by firm level data. In particular, we analyze if there is an inverted U-shaped relation between competition and R&D. Results show that the inverted U-shaped relation is supported by the Herfindahl index but not by the price cost margin. Using the Herfindahl index results suggest that breaking up monopolies increases R&D while further increases in competition most likely leads to reduced R&D. Comparing different estimators, we find that time-series based estimators typically result in less clear-cut results, probably driven by a lack of time series variation in measures of competition.

Keywords: R&D; Competition; Firm size; Spillovers
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1. Introduction

Does increased competition increase or decrease firm R&D? According to Schumpeter (1934) the monopoly deadweight loss is the price we have to pay in order to stimulate firms to perform R&D. Moreover, R&D is a major factor driving technological change and economic growth. Therefore, if Schumpeter's proposition holds, increased competition leads to less R&D and a lower rate of innovation and economic growth. The Schumpeterian argument is that uncertainty and competition reduces the expected pay-off from an investment in R&D and therefore contract firm R&D. This rather strong prediction has triggered a number of theoretical papers that in contrast to Schumpeter's view have shown that increased competition stimulates innovation and R&D. For example: Given perfect appropriability, Fellner (1951) and Arrow (1962) have shown that an innovating firm benefits more from an innovation if competition is strong. Scherer (1980) argues that lack of competition leads to bureaucratic inertia that discourages innovation. Porter (1990) states that competition is good for growth, because it forces firms to innovate in order to stay in business.

In an important paper, Aghion and Howitt, (1992) showed within a Schumpeterian based endogenous growth framework, how it is possible to establish a negative correlation between competition and R&D.[1] In 1999, they proceeded and showed how various changes within the set-up of their 1992-model may reverse the predicted negative impact of competition on R&D and growth. For example, if managers are not profit maximizing but rather just want to stay in business with as little effort as possible, increased competition will force managers to move the firm closer to the technological frontier, and as a result, R&D will increase. That is, an agency problem. Another mechanism that gives rise to a positive correlation between competition and R&D is the degree of neck-and-neckness in an industry. If an industry is characterized by neck-to-neck firms with similar technology, the gain due to an innovation is high. This is because instead of sharing the technological lead with its competitors, the firm will now be the single front technology firm. Hence, more product market competition boost firm R&D.

In the, Aghion *et al.* (2004) model, both the positive and negative impacts of competition on R&D are built into a single model which in turn yields an inverted U-shaped relation between competition and R&D. In addition, Aghion *et al.* (2004) show that the positive impact of competition

[1] Schumpeter made a distinction between actual and anticipated monopoly power. For a discussion of this issue, see e.g. Geroski (1990).

on R&D (escape competition effect) is strongest in leveled neck-to-neck industries.

In empirical analyses, the evidence on the impact of competition on R&D is mixed. An early study on this topic is Horowitz (1962) who found that competition contracts R&D. Other studies that find a negative correlation between competition and R&D are Hamberg (1964), Mansfield (1968), Kraft (1989), Crépon *et al*. (1998)[2] and Blundell *et al*. (1999).

In contrast to studies that find a negative correlation between R&D and competition there are studies that find a positive correlation. Examples are Mukhopadhyay (1985), Geroski (1990), Blundell *et al*. (1995)[3] and Nickell (1996). Because of these contradicting results one may suspect an underlying non-linear relation. Indeed, Sherer (1967) found evidence for an inverted U-shaped relationship between competition and R&D. Evidence for an inverted-U shaped relationship between competition and R&D has also been detected by Scott (1984), Levin *et al*. (1985) and Aghion *et al*. (2004).

We test whether predictions of the Aghion *et al.* (2004) model are supported by data. More specifically, ask whether there is an inverted U-shaped relation between competition and R&D and if the positive escape competition effect of competition on R&D increases with respect to the degree of neck-to-neckness. In addition we analyze robustness of results with respect to the use of different estimators and measures of competition. To achieve this we use Swedish firm level data covering the Swedish manufacturing industry spanning the period 1990 - 2000.

Results are sensitive with respect to choice of measure of competition. The inverted U-shaped relation is supported by the Herfindahl index, (H) but not by the price cost margin, (PCM). Using the Herfindahl index results suggest that breaking up monopolies increases R&D while further increases in competition most likely leads to reduced R&D. Comparing different estimators we find that time-series based estimators typically result in less clear-cut results, probably due to a lack of time series variation in measures of competition.

The paper is organised as follows: section 2 gives a short overview of related research. Data, variables, theoretical predictions and estimation issues are discussed in section 3; Section 4 contains the econometric results and section 5 concludes.

[2] The main goal of the Crépon *et al*. study is not to study competition and R&D but rather to link R&D, innovation and productivity.

[3] Blundell *et al*. find that dominant firms innovate more than non-dominant firms while industry concentration dampens innovative activity.

2. Related literature

As firm level data has become increasingly available, the subject of study has gradually changed from the industry to the firm. Despite the change of unit of observation there is no consensus on the shape of the relation between competition and R&D. Below we survey a number of studies on competition and R&D sorted with respect to method of estimation and measure of competition. This may reveal whether there is a systematic relation between results and the choice of estimator/measure of competition.

Nickell (1996), Aghion et al. (2004) and Mulkay et al. (2004) all use fixed effects, GMM or first differenced OLS, or a combination of these estimators on US, UK and French firms. These estimators typically wash out fixed effects and uses time series information only. Despite this similarity, results do not point in the same direction. Nickell finds that increased concentration increases productivity growth in UK-based companies, Aghion et al. (2004) find robust evidence for an inverted U-shaped relation between product market competition and innovation in a sample of 330 UK firms, while Mulkay *et al.* find that profits boost R&D in US firms but find no significant impact on French firms.

If differences in results not are driven by choice of estimator, the measure of competition may play a role. A commonly used measure of competition is the degree of market concentration measured as the market share held by the three or four largest firms in an industry. Studies that use market concentration as measure of competition do not all come up with similar conclusions. For example, Kraft (1989) in a study of innovation by West German firms find that increased market concentration boosts firm R&D. Crépon *et al.* (1998), apply a Tobit analysis and discrete choice models on French manufacturing firms and find that increased market shares both increase the probability that a firm performs R&D, and for R&D performers, boost R&D.[4] Slightly weaker conclusions are drawn by Mansfield (1983). Mansfield applies the change in market concentration on industry innovation and concludes that an increased rate of technological change often is associated with increased competition. Geroski (1990), using both Tobit as well as OLS models on 4 378 innovations in the UK find no support for the hypothesis that competition is bad for innovation and growth. Blundell *et al.* (1995) apply the degree of market concentration. Using firm level data on innovation in UK firms, they find

[4]The main purpose of the Crépon *et al.* study is not to analyze the impact of competition on R&D but rather to link R&D, innovation and productivity.

that dominant firms tend to innovate more than non-dominant firms while increased market competition at the same time dampens innovative activity. In a classical study on industry-level R&D and market concentrations, Sherer (1967) detects an inverse U-shaped relation between market concentration and R&D.

The uncertainty in R&D, firm survival and the degree of price volatility are closely related to the incentive to perform R&D. Anglemar (1985) finds that the impact of market competition on R&D crucially depends on the level of uncertainty in R&D and how difficult it is to imitate a new technology. To be precise, Anglemar finds that if the uncertainty in R&D is low and imitation is difficult, increased market concentration leads to less R&D (and vice versa). In an analysis of West German manufacturing firms, Smolny (2003) associates low price volatility with low competition. Using a Tobit analysis, he draws the conclusion that market power promotes innovation.

With these diverging results it seems plausible that a study of the impact of competition on R&D benefit from using more than one estimator and one measure of competition. Such an approach reveals the robustness of results and more reliable conclusions can be drawn.

3. Theoretical predictions, variables and econometric issues

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 firm-level R&D and which have been used for that purpose in the empirical literature. However, the Schumpeterian model has proved to be flexible and has been extended in various directions. We test predictions of the Aghion *et al*. (2004) model. Aghion *et al.* (2004) use a Schumpeterian framework and derive an inverted U-shaped relation between competition and R&D. The mechanism behind this curve is the following: firms compare the expected profit of pre and post-innovation rents. If competition decreases, pre-innovation rents less than post-innovation rents, increased competition fosters innovation. Hence, if competition increases, firms might escape competition by innovating. However, if competition is fierce the negative Schumpeterian effect of competition on R&D dominates the positive escape competition effect. Put together, these two contradicting forces give rise to an inverse U-shaped relationship between competition and R&D.

In addition, the positive effect of competition on innovation and R&D is strongest in leveled industries characterized by neck-to-neck firms with similar technological level and unit costs. The intuition is that in leveled industries, an incremental increase in productivity helps the firm to reap market shares from a large number of competitors. Hence in leveled industries the positive escape competition effect of competition on R&D is stronger (steeper) than in unleveled industries. Finally, the model predicts that the expected technology gap in an industry increases with the degree of competition.[5]

The theoretical model is intuitive and straightforward but rather complex to solve analytically. Typically, no closed-form solution is reachable and one has to rely on numerical solutions and simulations, we therefore focus on the implications of the model and test if they are supported by data.[6]

3.1 Variables

R&D

The central variable of the Aghion *et al*. (2004) model is innovation. To proxy innovation, researchers typically use data on: patent, R&D spending or productivity. At a first glance patent data might be an appropriate measure. However, the patenting propensity varies enormously across firms and industries. In some industries the patenting procedure might be even longer than the economic payoff of an innovation. Some firms may both innovate and perform relatively much R&D without that shows up in the patent statistics. Therefore, patent data might be more appropriate in an analysis on a limited number of industries. Productivity growth is an alternative output measure of innovation. In practice, productivity growth is not only related to innovation but also to investments and embodied technological change (Stoneman, 1983). Moreover, given imperfect competition, commonly used measures of TFP are biased.[7] Therefore, our preferred measure of innovation is R&D expenditures.[8]

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[5] Since we build on a well-known model, the description is kept brief. See Aghion and Howitt (2004) for details.

[6] This approach is also taken by Aghion *et al*. (2004).

[7] See e.g., Klette and Griliches (1996) and Klette (1999).

[8] R&D can be seen as an input in the innovation process where innovations and patents are the output. Increased input –R&D- is therefore expected to give rise to increased output, that is, innovations.

Competition

Competition is a non-monetary concept which makes it hard to measure. We apply two measures of competition – one at the industry and one at the firm level reflecting the degree of competition from different perspectives, thus allowing us to evaluate the robustness of the association between R&D and competition. Our first measure of competition is the Herfindahl index *(H)*. More competitors and/or more equally distributed market shares result in a lower value of the Herfindahl index, indicating increased competition. The Herfindahl index is more appropriate for large economies (where the domestic market is the main market) than it is for small economies and small markets.[9]

As an alternative and as a robustness test we use the price cost margin, (PCM). The PCM measure the mark-up that firms charge. A low degree of product market competition results in high mark-ups. Contrary to the Herfindahl index, changes in PCM are directly related to the firms pricing behavior.[10] It is not a trivial matter to decide on the proper level of aggregation for the PCM. On the one hand, competition is easily thought of as an industry property. On the other hand, two firms active in the same industry might produce products that do not compete in the same market. Firms often try to create their own segment to profile their product and escape competition. Therefore, we apply the PCM at the firm level.

An issue not often discussed in the context of the measurement of competition is globalization. For many firms, the final good market is located in both the home country and abroad while the R&D activity may be concentrated to one country. Hence, competition on foreign markets may affect the amount of R&D performed in the home market. Therefore, if firms are unable to segment markets, the price cost margin might be preferable to the Herfindahl index. This is because the PCM might be a function of not only the degree of competition in the home market but also of competition on foreign markets.

Variation in the measured level of competition may a have different interpretation in the cross-sectional and time-series dimension. In the cross-section, a high PCM (or Herfindahl index) might be the outcome of scale effects or lack of competition, or a combination of these. In the time series dimension we can ignore scale-effects and fixed factors that affect firm R&D. A new entrant in an industry – implying a decreasing scale of the Herfindahl index - will only be related to the measured level of competition in the same industry at a specific point in time. Therefore, in the time series

[9] For example, the US competition authorities use the Herfindahl index as a guideline for making decisions on approving mergers and acquisitions, see e.g. FTC (1995).

[10] For a survey of the theory of oligopoly, competition and price, see e.g. Weiss (1989).

dimension the dynamics of competition variables has a clear interpretation. However, this comes at a price. First, we lose potentially valuable cross-sectional information. Second, Davies and Geroski (1997) point out that even if individual firms' market shares vary over time and competition is fierce, industry based measures of competition might be rather stable. This leads to low time-series variation in data, large standard errors and potentially an under-evaluation of competition. As expected, our measures of competition have a larger cross sectional than time (within) variation.[11]

It is well known that the PCM may be endogenous. Tybout (2003) discuss the impact of import competition and the return on capital on firms' pricing behavior. In addition, Clarke and Davies (1982), analyze how the Herfindahl index and PCM are related to efficiency differences among firms in the same industry. In the analysis, the PCM is treated as an endogenous variable.[12]

Technology spillovers

Firms do not rely on internally generated technology only, outside technology is also important. In this context, the importance of technology spillovers as a vehicle for innovation and productivity growth becomes clear. In a classical paper, Griliches (1992) points at substantive and significant spillovers associated with trade.[13] We analyse imported technology spillovers using R&D weighted I/O spillovers.[14]

Spillovers may not only stem from import, domestic conditions also matters. A firm distant from the technology frontier may have more outside information to absorb than the leading-edge firm. We capture this type of spillover by means of a technology transfer (technology gap) parameter, $(A-gap)_{mt}$ indicating the distance to the technology frontier.[15]

The escape competition effect and neck-to-neckness

The Aghion *et al*. (2004) model predict that the escape competition effect is strongest in leveled industries. That is, increasing competition is expected to boost R&D by most in leveled industries. We test this hypothesis by

[11] Herfindahl index; $\sigma_{be} = 2556$, $\sigma_{w} = 1756$. PCM; $\sigma_{be} = 0.92$, $\sigma_{w} = 0.35$.

[12] We instrument PCM with industry import penetration, capital intensity, Herfindahl index, TFP, fixed industry effects and period dummies.

[13] Wolfgang Keller, in an array of papers (see e.g. Keller 1997, 2000, 2002a, 2002b), has studied both national and international technology spillovers. In line with Griliches (1992) he finds strong support for the existence of technology spillovers.

[14] For a similar approach, see e.g. Coe and Helpman (1995). For details on variable construction, see Appendix.

[15] For a similar approach, see e.g. Van Reenen *et al*. (2000) and Aghion *et al*. (2004). For details on variable construction, see Appendix.

including an interaction between the intra-industry technology gap and the degree of competition, $(A - gap * H)_{mt}$ and perform the analysis on neck-to-neckness firms.

Firm size

The perhaps most well-studied variables causing firm R&D 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. We measure firm size as relative employment of the *i*th firm to the industry average and test if proportionality can be rejected or not (see Girma and Görg, 2003).[16]

Human capital

The importance of human capital in the innovation process is stressed in the endogenous growth theory.[17] In the Aghion *et al*. (2004) model, labor is homogenous and each firm chooses its allocation of labor to maximize the current value of profits. However, it is plausible to argue that total firm R&D also depends on the skill composition of the labor force. To control for firms' skill composition we include the wage share to skilled workers (workers with at least post secondary education). An econometric issue is the direction of causality; does firms' R&D depend on their human capital abundance or vice versa? We tackle possible endogeneity by way of an instrumental variable approach[18] using lagged values of the firms' wage share to skilled workers as well as industry- and time dummies as instruments. In addition, the skill composition may be dependent on the level of competition. Including the human capital variable does not allow the impact of competition on R&D to incorporate human-capital adjustments. As a robustness test we re-estimate the model excluding the human-capital variable, thus, allowing changes in competition to pass over to the R&D expenditures through adjustments of the workforce.

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[16] Relating competition to firm size may incur a spurious relationship. We adjust for endogeniety using a set of lagged values of firm size, industry- and time dummies as instruments.

[17] *See e.g. Grossman and Helpman (1991), Romer (1990) and Jones (1995).*

[18] 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)).

Industry dummies
Technological opportunity is about the possibility of converting an innovation to a new enhanced product or production process. Many researchers have realised the importance of this concept while still lacking a clear and precise understanding of how to conceptualise and measure it. Geroski (1991b) argues that industries in the early phase of the product cycle may be characterised by high rates of innovation and a high level of technological opportunity which stimulates R&D. We lack a precise tool for describing the product cycle and follow Geroski (1990) in treating technological opportunity as an unobservable industry component[19].

Ownership
For many firms, the cost of performing R&D is substantial and the possibility to collect risk capital is crucial in financing R&D projects. One may argue that public firms face fewer obstacles than private ones in collecting such capital and controlling ownership may therefore be important. Moreover, studies of multinational firms show that most of their innovative activity tends to be performed in the home country see e.g. Cantwell (1992). To capture the impact of ownership we include a "public-owned" and a "foreign-owned" dummy.

To test implications of the Aghion et al. (2004) model we specify a semi-loglinear relationship between firm R&D and the independent variables. The estimated baseline specification takes the form:

$$\begin{aligned}&\log(\mathrm{R\&D}_{imt}) = \alpha_0 + \alpha_i + \alpha_t + \beta_1 \log(\mathrm{Competition}_{imt})\\&+\beta_2 \log(\mathrm{wH}_{imt}) + \beta_3(\mathrm{A-gap}_{imt-s}) + \beta_4 \log(r^F_{mt-s}) + \beta_6(\mathrm{Size})_{imt}\\&+\beta_5 D^{private}_{imt} + \beta_6 D^{Foreign}_{imt} + \varepsilon_{imt} \quad ; \quad \varepsilon_{imt} \sim iid(0, \sigma^2_\varepsilon)\end{aligned} \tag{3.1}$$

where wH is the wage share to skilled workers in firm *i* in industry *m* at time *t*, $A-gap$ is the distance to the technological leader, r^F is imported technology spillovers, *Size* is relative employment to the industry average, ownership is captured by a private and a foreign ownership dummy, competition is captured by the Herfindahlindex and the price cost margin and ε is the classical error term.

[19] Similarly, we lack patent statistics and therefore treat the appropriability conditions as an unobservable characteristic captured by industry-/fixed effects.

3.2 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 2000. *RAMS* mainly contain information on employees' level of education and wages while *FS* contain information about firms' inputs and outputs.

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 it 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.[20]

R&D is not evenly distributed across industries. Table 1 reveals that 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 only 0.2 percent. Obviously, the importance and impact of a policy intended to affect firm R&D may be very different across industries.

Table 1: R&D intensities by industry (in percentages), 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 number of observations, (firms with R&D>0) 2258					

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

[20] 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 the context of statistical reliability, the bi-annually collected Research Statistics is of higher quality but has less coverage. The *RS* and *FS* data yield similar results but the *RS* reduces the sample size by more than 50%.

4. Results

In Table 2 we present results ignoring any potential non-linearity in competition and in Figure 1 we depict results from regressions allowing for a non-linear relation between competition and R&D using different estimators and measures of competition. In Tables 3 and 4 we proceeds by analyzing whether the escape competition effect is strongest is in leveled industries and perform a sensitivity analysis of results with respect to inclusion/exclusion of human capital variables and instrumental variables.[21]

Results in Table 2 indicate that competition tends to contract R&D, supporting the classical Schumpeterian view.[22] This result is robust with respect to the inclusion/exclusion of fixed industry effects, spillover variables and choice of estimator. To explore whether an inverted U-shaped relation is present, we proceed and apply a second order polynomial of the competition variables and two measures of competition. The results are depicted in Figure 1.[23]

Focusing on the Herfindahl index, results in Figure 1 supports the hypothesis of an inverted U-shaped relation between competition and innovation. However, replacing the Herfindahl index for the PCM yields a negative relation between competition and R&D. Hence, using the PCM only the Schumpeterian effect is detected, while the positive escape competition effect vanishes. Moreover, using the fixed effect estimator the relation between competition and R&D becomes insignificant. The reduced significance is probably driven by low time-series variation in our measures of competition. Hence, results are in line with arguments made by Davies and Geroski (1997).

The difference in results using the Herfindahl index and the PCM may be driven by a number of reasons. First, starting from a low level of competition a decreasing Herfindahl index *ex ante* suggests increased competition, and a firm might escape competition by increasing its R&D. However, a reduced PCM indicates an *ex post,* realized reaction of competition. One may therefore argue that a realized change in the price cost margin immediately takes the firm to the segment where the Schumpetarian effect dominates. As seen in Figure 1, the escape competition effect only dominates the Herfindahl index at low levels of competition (Herf > 4200), that is, in monopoly-duopoly industries.

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[21] The instrumented variables are *PCM, Size and wH*.

[22] This result also holds for the Herfindahl index.

[23] For parameter estimates, see Table A3.

Table 2: Regression results R&D versus competition. Competition measure - price cost margin.

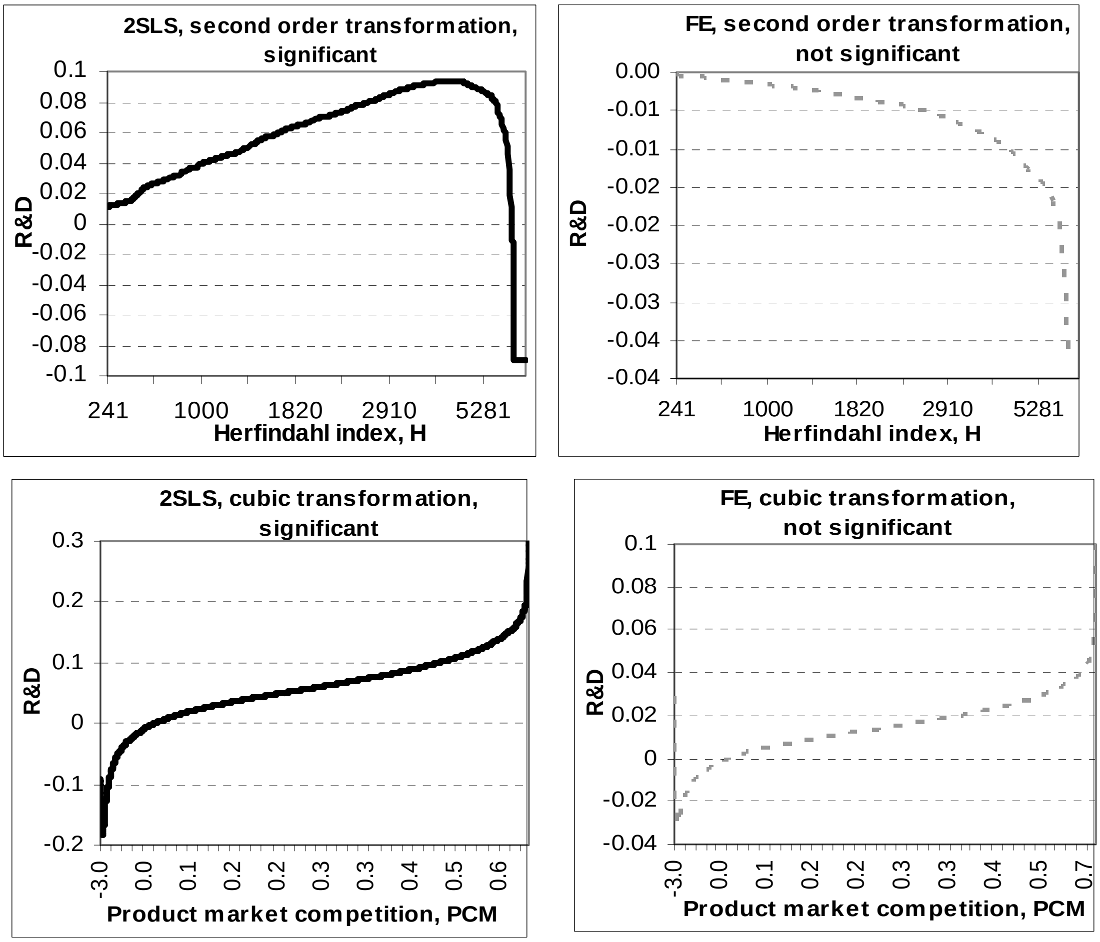
	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5
Variables	**FGLS**	**2SLS**^{A}	**2SLS**^{AB}	**2SLS**^{A}	**2SLS-FE**
	[Prais-Winsten]	[Prais-Winsten]	[Prais-Winsten]	[Prais-Winsten]	[AR1]
log(PCM) (Competition)	0.11 (t) (0.000)***	0.71 (t) (0.000)***	1.02 (t) (0.000)***	1.15 (t) (0.000)***	0.40 (t) (0.046)**
log(Size) (Rel.employment)	0.91 (t) (0.000)$^{***\,!!!}$	0.91 (t) (0.000)$^{***\,!!!}$	1.08 (t) (0.000)$^{***\,!!}$	1.18 (t) (0.000)$^{***\,!!!}$	0.45 (t) (0.000)$^{***\,!!!}$
log(wH) (Human cap)	1.15 (t) (0.000)***	1.31 (t) (0.000)***	1.16 (t) (0.000)***	1.03 (t) (0.000)***	0.39 (t) (0.000)***
A-gap (Tech gap)	- -	- -	0.01 (t-3) (0.000)***	0.005 (t-3) (0.006)**	0.0002 (t-1) (0.856)
log(r^F) (Spillovers)	- -	- -	0.73 (t-1) (0.000)***	0.71 (t-1) (0.000)***	0.26 (t-1) (0.004)**
Government Dummy	0.14 (t) (0.090)*	0.09 (t) (0.288)	0.08 (t) (0.451)	0.01 (t) (0.925)	0.011 (t) (0.335)
Foreign Dummy	0.23 (t) (0.000)***	0.25 (t) (0.000)***	0.10 (t) (0.040)**	0.10 (t) (0.043)**	0.05 (t) (0.494)
Industry effects	No	No	No	Yes***	No
Time effects	Yes***	Yes***	Yes***	Yes***	Yes***
Firm effects	No	No	No	No	Yes***
Hausman-Wu	-	-	-	-	368.9***
Breusch-Pagan	-	-	-	-	5597.6***
R^2 adjusted	0.93	0.94	0.95	0.96	-
- Within	-	-	-	-	0.41
- Between	-	-	-	-	0.01
- Overall	-	-	-	-	0.01
Obs	8194	6795	4361	4361	5082

Notes: p-values within brackets. ***, **, * 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 size variable.

^{A} We allow for a first order panel specific autocorrelation and heteroscedasticity in the error term.

^{B} After adjusting for endogeneity, Wu-Hausman tests indicate that we continue to have a minor problem of endogeneity.

Figure 1: The estimated relation Competition versus R&D.



Note: The figures are derived from second order specifications of the 2SLS and FE-model specifications in models 4 and 5 in Table 2 respectively, see Appendix for parameter estimates.

Switching from the 2SLS estimator to the fixed effect estimator similar curves appears but all significance vanishes. Hence, results depend on what measure of competition we choose and the significance is affected by choice of estimator.[24]

The PCM may be influenced not only by domestic producers but also by the degree of competition from foreign producers and competition on foreign markets while the Herfindahl index only takes the number of domestic producers and the distribution of market shares among these into account. To add control for the impact of import competition when using the Herfindahlindex we in model 8 (Table 3) complement the estimation

[24] Aggregating the PCM to the industry level yields similar curvature as for the firm level and a drop in significance.

with the degree of industry import penetration. Results show that the inverted U-shaped relationship between the Herfindahl index and R&D is stable irrespective of whether we take import competition into account or not. The estimated impact of industry import penetration is negative and sig-

Table 3: The escape competition effect and human capital. Competition measure - Herfindahl index.

	Mod 6	**Mod 7**	**Mod 8**	**Mod 9**	**Mod 10**
				[Neck to neckness][q]	[Neck to neckness][q]
Variables	**OLS**	**2SLS**[A] [Prais-Winsten]	**2SLS**[A] [Prais-Winsten]	**2SLS** [Prais-Winsten]	**2SLS** [Prais-Winsten]
Herf (Competition)	$1.0E^{-4}$ (t) $(0.000)^{***}$	$4.5E^{-5}$ (t) $(0.013)^{**}$	$3.6E^{-5}$ (t) $(0.051)^{*}$	$6.7E^{-5}$ (t) $(0.001)^{**}$	$9.8E^{-5}$ (t) $(0.000)^{***}$
$Herf^2$ (Competition)	$-1.12E^{-8}$ (t) $(0.000)^{***}$	$-5.53E^{-9}$ (t) $(0.008)^{**}$	$-4.53E^{-9}$ (t) $(0.032)^{**}$	$-8.82E^{-9}$ (t) $(0.000)^{***}$	$-1.00E^{-8}$ (t) $(0.000)^{***}$
*A-gap*H (Complementarity)*	- -	- -	- -	- -	$-5.1E^{-5}$ (t) $(0.000)^{***}$
log(M/Q) (International trade)	- -	- -	-0.05 (t) $(0.085)^{*}$	- -	- -
log(firm size) (Rel.employment)	1.19 (t) $(0.000)^{***\,!!!}$	1.28 (t) $(0.000)^{***\,!!!}$	1.19 (t) $(0.000)^{***\,!!!}$	1.17 (t) $(0.000)^{***\,!!!}$	1.17 (t) $(0.000)^{***\,!!!}$
log(wH) (Human capital)	1.12 (t) $(0.000)^{***}$	- -	1.00 (t) $(0.000)^{***}$	1.12 (t) $(0.000)^{***}$	1.14 (t) $(0.000)^{***}$
A-gap (Technology gap)	0.005 (t-2) $(0.013)^{**}$	0.004 (t-3) $(0.008)^{**}$	0.004 (t-3) $(0.018)^{**}$	0.003 (t-3) (0.163)	0.003 (t-3) (0.150)
$log(r^F)$ (Spillovers)	0.14 (t-2) (0.113)	0.87 (t-1) $(0.000)^{***}$	0.72 (t-1) $(0.000)^{***}$	0.69 (t-1) $(0.000)^{***}$	0.64 (t-1) $(0.000)^{***}$
Government dummy	-0.17 (t) $(0.055)^{*}$	0.07 (t) (0.575)	0.04 (t) (0.740)	0.17 (t) (0.118)	0.20 (t) $(0.021)^{**}$
Foreign dummy	0.07 (t) $(0.043)^{**}$	0.13 (t) $(0.009)^{**}$	0.10 (t) $(0.026)^{**}$	0.13 (t) $(0.009)^{**}$	0.12 (t) $(0.012)^{**}$
Industry effects	Yes***	Yes***	Yes***	Yes***	Yes***
Time effects	Yes*	Yes***	Yes***	Yes***	Yes***
R^2 adjusted	0.68	0.95	0.95	0.95	0.96
Observations	6246	5108	5022	4226	4226

[q] Neck-and-neckness competition is defined when A-gap < 2.26 (The mean value of Technology gap).

Notes: p-values within brackets. ***, **, * 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 *log*(σ) variable).

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

nificant at the 10 percent level of significance indicating that competition from abroad contract firm R&D. That is, the traditional Schumpeterian effect of competition on innovation dominates.

The Aghion et al. (2004) model suggests a complementarity between the degree of neck-and-neckness and competition. The positive escape competition effect is supposed to boost R&D by most when firms compete neck-to-neck. We test this proposition by fixing the regressions to the interval where the technology gap is below the average, i.e. where firms are close to each other in the technology space. In support of the model, using the Herfindahl index, the inverse U-shaped relation is sharpened[25]. Both the first and second order polynomial coefficient increase in absolute value. In addition, as a direct test of complementarity, in models 10 and 15 we append an interaction between competition and the degree of neck-and-neckness. Results point in the same direction. Using the Herfindahl index we find support for a positive interaction between competition and neck-and-neckness on R&D. However, when using the PCM we do not find any support for complementarities.

A third prediction of the model is that the expected technology gap increases with competition. This suggests a negative correlation between the technology gap and the degree of competition. This hypothesis is supported by both competition variables.[26]

There are of course other variables than competition that cause R&D investments. One of the most classical ones, stemming from Schumpeter's earlier work in the 1940s is firm size. In line with the vast majority of work in this field we find the average R&D elasticity with respect to firm size to be close to unity (0.9-1.3). However, using the fixed effect estimator the estimate drops to 0.40.[27] Hence, no strong scale effect in R&D is detected and we note that results may alter depending on choice of estimator.

The most central component in the innovation process is human capital.[28] Analyzing the impact of firms' skill composition on R&D we find that the wage share of skilled workers is a highly significant determinant of R&D. The estimated elasticity is slightly above unity indicating that human capital-intensive firms perform relatively much R&D.[29] Because wages to R&D personnel are included in the R&D expenditures we use an instrumental variable approach. Results are significant and insensitive to

[25] Test of coefficients of H and H^2 between neck-to -neckness specifications and full models indicate insignificant differences at the 5 percent level.

[26] See the Correlation matrix, Appendix.

[27] 0.45 when using the Herfindahl index.

[28] See e.g. Aghion & Howitt 1999.

[29] The 2SLS estimated elasticity span the interval 1.03-1.31.

choice of IV-matrix indicating a robust relation between human capital and firm R&D.

In models 7 and 13 we exclude the human capital variable from the analysis. By excluding this variable we allow for the indirect impact of com-

Table 4: The escape competition effect and human capital. Competition measure - price cost margin.

	Mod 11	**Mod 12**	**Mod 13**	**Mod 14 [Neck to neckness]**	**Mod 15 [Neck to neckness]**
Variables	**OLS**	**2SLS**[A] [Prais-Winsten]	**2SLS**[A] [Prais-Winsten]	**2SLS** [Prais-Winsten]	**2SLS** [Prais-Winsten]
PCM (Competition)	0.006 (t) (0.560)	0.21 (t) (0.000)***	0.38 (t) (0.000)***	0.35 (t) (0.000)***	0.29 (t) (0.000)***
PCM^2 (Competition)	4.84E^{-5} (t) (0.753)	0.06 (t) (0.043)**	0.05E^{-9} (t) (0.118)	0.04 (t) (0.221)	0.08 (t) (0.027)**
*A-gap*PCM (Complementarity)*	- -	- -	- -	- -	0.06 (t) (0.204)
log(firm size) (Rel.employment)	1.21 (t) (0.000)*** !!!	1.20 (t) (0.000)*** !!!	1.30 (t) (0.000)*** !!!	1.17 (t) (0.000)*** !!!	1.17 (t) (0.000)*** !!!
log(wH) (Human capital)	1.17 (t) (0.000)***	1.07 (t) (0.000)***	- -	1.11 (t) (0.000)***	1.10 (t) (0.000)***
A-gap (Technology gap)	0.005 (t-2) (0.015)**	0.005 (t-3) (0.005)**	0.006 (t-3) (0.001)**	0.004 (t-3) (0.042)**	0.004 (t-3) (0.043)**
$log(r^F)$ (Spillovers)	0.08 (t-3) (0.344)	0.72 (t-1) (0.000)***	0.83 (t-1) (0.000)***	0.52 (t-1) (0.000)***	0.52 (t-1) (0.000)***
Government dummy	-0.017 (t) (0.871)	0.02 (t) (0.872)	0.04 (t) (0.776)	0.18 (t) (0.076)*	0.17 (t) (0.101)
Foreign dummy	0.08 (t) (0.030)**	0.10 (t) (0.031)**	0.10 (t) (0.054)**	0.11 (t) (0.039)**	0.11 (t) (0.037)**
Industry effects	Yes***	Yes***	Yes***	Yes***	Yes***
Time effects	Yes***	Yes***	Yes**	Yes***	Yes***
R^2 adjusted	0.69	0.96	0.95	0.96	0.96
Observations	5164	4361	4361	3481	3481

[q] Neck-and-neckness competition is defined when A-gap < 2.26 (The mean value of Technology gap).

Notes: p-values within brackets. ***, **, * 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 *log*(σ) variable).

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

petition on the allocation of human capital to pass over to R&D. This is a less restrictive model formulation. Excluding the human capital variable does not change the results.

It is well documented that outside knowledge contributes to firms' knowledge stock. One channel for outside knowledge to reach firms knowledge stock is through knowledge spillovers. Spillovers may follow many paths; some are related to international trade flows and input-output linkages while others may be domestic horizontal spillovers. Accordingly, we distinguish between local and international spillovers. For each firm, we analyze domestic spillovers using the technology gap to the technological leader in the industry. The technology gap measure is positive and significant in most of the regressions. The conclusion is that due to horizontal domestic spillovers, laggards tend to undertake more R&D than what would have been the case in the absence of such spillovers.

R&D investments are not only affected by local spillovers, international spillovers also matters. We capture international trade related spillovers by filtering R&D weighted imports through the I/O-matrix. International spillovers are positive and significant in all specifications irrespective of choice of estimator. Results point at an estimated elasticity in the interval of 0.3-0.7, indicating the existence of substantial spillovers from abroad. Hence, results indicate that foreign knowledge may be particularly important for a small economy where the domestic knowledge stock is small relatively to the world knowledge stock. Significant, trade related knowledge spillovers are also found by e.g. Coe Helpman (1995) and Keller (2000, 2002b).

Firm ownership may affect the possibility of funding R&D. In a policy sense it is important to analyze whether publicly-owned firms *cet. par.* spend more on research than privately owned firms. Results do not reveal any differences between publicly- and privately-owned firms. Finally, studies of multinational- and foreign-owned firms have pointed out that, for many firms, most of the innovative activity is performed in the home country. However, results indicate that, if anything, foreign-owned firms spend more on R&D than domestic ones. This might be taken as an indication of Sweden having a comparative advantage in R&D and human capital-intensive production. Similar results are obtained in Gustavsson and Kokko (2003) and ITPS (2004).

5. Summary and conclusions

There is no consensus on how competition affect firm R&D. Different studies comes to diverging results. One may therefore suspect a non-linear relation between competition and R&D. Under fairly general conditions, Aghion *et al.* (2004) derive a Schumpetarian model where an inverted U-shaped relation is one of the major predictions. Secondly, the model predicts that the positive escape competition effect of competition on R&D is strongest in leveled industries. That is, where firms' technology and unit costs are similar to each other. Thirdly, the model predicts that the expected technology gap within an industry increases with competition. Using firm level data we test predictions of the Aghion *et al* and investigate the robustness of the relation between competition and R&D taking different estimators and measurers of competition into account.

Results reveal a complex relation between measures of competition and R&D. Using the Herfindahl index we find strong support for the Aghion *et al*. (2004) model. A significant inverted U-shaped relation between competition and R&D is detected. In addition, the inverse U-shaped relationship between competition and R&D investments is robust with respect to the inclusion/exclusion of other variables. We also find the positive escape competition effect of competition on R&D to be strongest in leveled industries. Finally, the model points at, as expected, a positive correlation between the technology gap in an industry and the level of competition. Hence, at a first glance the Aghion *et al*. model stands up well when confronted with data.

However, if the Herfindahl is replaced by the price cost margin, results break down. First, no positive effect of competition on R&D is detected, only the negative Schumpeterian effect survives. Secondly, no positive interaction effect of the degree of neck-and-neckness and competition on R&D detected. Third, as for the Herfindahl index, using fixed effect estimators, the effect of competition on R&D typically becomes insignificant. The reduced significance support arguments made by Davies and Geroski (1997). Davies and Geroski argue that despite a relatively high within-industry turbulence of firm exit and market shares, aggregate measures of concentration and competition may be fairly stable over time. Hence, in the time series dimension there is not much information so that one gets large standard errors and insignificant estimates.

There may be several explanations why results differ depending on choice of estimator. One reason may be measurement errors. There may also be fundamental differences between the Herfindahl index and the price cost margin. Given non-segmented markets the price cost margin may be affected by competition from both domestic- and foreign-based producers while the Herfindahl index is only determined by the number of domestic competitors and the distribution of market shares. In addition, changes in the Herfindahl index are closely related to an *ex ante* expected and not necessarily realized change in competition. A change in a firms' PCM, on the other hand, is an *ex post* realized reaction to changes in the environment. Hence, a decrease in the PCM is a stronger indication of increased competition than a decreasing Herfindahl index. Initially, true competition that is unobserved may increase a certain amount before firms' adjust their PCM. Therefore, a decreased PCM may immediately bring the firm to the segment where the negative Schumpeterian effect of competition on R&D dominates the positive escape competition effect. Further, both in this analysis and the analysis made by Aghion *et al.* the escape competition effect dominates the negative Schumpeterian effect at very low levels of competition only. Results indicate that only breaking up monopolies leads to increased R&D. If competition is moderate or higher, results suggest that increased competition most likely decreases firm R&D. Hence, the positive effect of competition on R&D is most likely to be found in industries with a low level of competition.

To evaluate the generality of these results it would be interesting to see if similar patterns as found here apply for other countries. This would not only indicate the robustness of results but also serve as an indication of the degree of heterogeneity across countries with respect to the impact of competition on innovation and R&D. We therefore look forward to future work on this topic.

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Appendix

Variable definitions and construction

Below we present additional descriptions of selected variables. Our choice of subscript is defined as follows; i = firms, t = time index, m = industry according to 3-digit SNI 92.

1. R&D: Total Research and Development expenditures[30] in 1990 constant prices. Source: Statistics Sweden/Research Statistics.

2. Herfindahl index: calculated at the 3-digit level. Source: Statistics Sweden/Financial Statistics.

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

3. Import penetration. Source: Statistics Sweden/Trade Statistics.

$$IMC_{mt} = \left(\frac{M}{Q} \right)_{mt}$$

4. TFP: Total factor productivity. (measured by means of Törnqvist index[31]). Source: Statistics Sweden/Financial Statistics.

5. Technology gap, maximum TFP for the *i*th firms in the *m*th industry. Source: Statistics Sweden/Financial Statistics.

$$A - gap_{it} = \frac{TFP_{jmt}^{max} - TFP_{it}}{TFP_{it}} \text{, where j = leading firm}$$

6. Price cost margin. Source: Statistics Sweden/Financial Statistics.

$$PCM_{it} = \frac{Value\ added_{it} - payroll_{it}}{Value\ added_{it}}$$

[30] 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 by Statistics of Sweden).

[31] See Gunnarsson and Mellander (1999)

7. Size parameter. Source: Statistics Sweden/Financial Statistics.

$$\sigma_{imt} = \frac{employees_{imt}}{M^{-1}\sum_{i=1}^{M} employees_{imt}}$$

8. wH[32]: Share of total wage-sum to employees with post secondary education. Source: Statistics Sweden/Regional Labor Statistics.

9. International R&D spillovers. Derived from the international I/O tables, computed at 2-digit level. Source: SCB/Financial Statistics, SCB/National accounts and ANBERD.

$$r_{mt}^{F} = \sum_{l} b_{ml}^{F} \left(\frac{R\,\&\,D}{Y} \right)_{lt}^{F}$$

10. D^{Public}: Government dummy for publicly owned firms. Source: Statistics Sweden/Financial Statistics.

11. $D^{Foreign}$: Foreign dummy for foreign-owned firms. Source: Statistics Sweden/Financial Statistics.

Table A1: Deflators:

Deflator	*Description*	*Source*	*variables*
PPI	*Aggregated producer price index*	*SCB homepage* [i]	*R&D*
PRODINDEX	*Disggregated producer price index*	*SCB homepage*	*Output and value added*
ITPI	*Disaggregated intermediate goods producer price index*	*SCB homepage*	*Intermediate goods and raw materials*
EPI	*Aggregated energy producer price index*	*SCB homepage*	*Energy*
BYGGINDEX	*Disaggregated construction producer price index*	*SCB homepage*	*Capital stocks of buildings and construction*
MASINDEX	*Disaggregated machinery producer price index*	*SCB homepage*	*Capital stocks of machinery and inventory*
IMPINDEX	*Disaggregated imported good producer price index*	*SCB homepage*	*Imports*
KPI	*Aggregated consumer price index*	*SCB homepage*	*Wages*

Notes: [i] www.scb.se

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

Table A2: Correlation matrix

	log(R&D)	*PCM*	*PCM^2*	*Herf*	*$Herf^2$*	*log(size)*	*log(wH)*	*A-gap*	*$log(r^F)$*	*Public*	*Foreign*
log(R&D)	1.00										
PCM	0.07	1.00									
PCM^2	0.08	-0.78	1.00								
Herf	0.21	-0.12	0.14	1.00							
$Herf^2$	0.13	-0.07	0.07	0.90	1.00						
log(size)	0.54	0.07	-0.02	0.09	0.08	1.00					
log(wH)	0.55	0.12	0.02	0.16	0.09	0.11	1.00				
A-gap	0.00	-0.12	-0.04	-0.07	-0.05	0.00	0.05	1.00			
$log(r^F)$	0.35	-0.15	0.19	0.09	0.01	-0.08	0.37	-0.05	1.00		
Public	0.04	-0.06	0.09	0.03	0.01	0.05	0.05	-0.00	-0.01	1.00	
Foreign	0.15	0.05	0.02	0.02	-0.00	0.09	0.15	-0.04	0.13	-0.10	1.00

Table A3. Sensitivity analysis, different measures of competition and estimators

	Firm-level measure	*Industry- level measure*	*Firm-level measure*	*Industry- level measure*
Estimator →	**2SLS**	**2SLS**	**FE-estimation**	**FE-estimation**
	PCM	Herfindahl index	PCM	Herfindahl index
1st order polynomial	0.21 (t) (0.000)***	$4.5E^{-5}$ (t) (0.010)**	0.05 (t) (0.412)	$-1.4E^{-6}$ (t) (0.945)
2st order polynomial	0.06 (t) (0.043)**	$-5.4E^{-9}$ (t) (0.008)**	0.02 (t) (0.290)	$-2.3E^{-10}$ (t) (0.916)

Note: The cubic 2SLS and FE-model specification corresponds to model 4 and 5 in Table 4 respectively.

Table A4. Variance decomposition

Variable	Overall- stdv	Within- stdv	Between- stdv
log(R&D)	2.11	0.70	1.94
log(PCM)	0.32	0.13	0.30
PCM	0.91	0.35	0.92
Herfindahl	2896.3	1754.5	2556.2
log(σ)	0.95	0.26	0.89
log(δ)	0.78	0.25	0.81
A-gap	16.4	12.5	12.9
$log(r^F)$	0.91	0.07	0.93

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