Service-sector competition, innovation and R&D

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ABSTRACT

The central prediction of the Aghion *et al.* (2005) model is an inverted U-shaped relation between innovation and competition. The model is built on the assumption of a product market and has not yet been empirically tested on service-sector firms. Using detailed firm-level data, we find the inverse U-shaped relation to hold for both small and large service-sector firms. However, non-exporting service firms deviate from the overall pattern. A more detailed breakdown of innovation expenditures shows that the inverse U-shaped pattern holds for both intramural R&D and training, but not for extramural R&D. Finally, as competition increases, small firms tend to seek more strategic alliances with competitors while large firms tend to decrease their collaboration with competitors. To some extent, the behavior of large firms can be due to their greater capacity to handle innovation projects internally and as competition increases, so does the payoff of an edge to competitors.

Keywords: R&D, innovation, competition, service sector
JEL classification codes: D40, L10, L60, O30

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1. Introduction

When thinking about competition and R&D, the manufacturing sector is often considered and the service sector ignored. However, in many rich developed countries, the size of the service sector has outgrown the manufacturing sector by a factor of about two. Despite the economic impact of the service sector, relatively little is known about service-sector innovation and how innovation in service-sector firms responds to competition. According to Schumpeter (1934), the monopoly deadweight loss is the price we have to pay to finance and stimulate firm R&D. That is, increased competition leads to less R&D and a lower rate of innovation and economic growth. The Schumpeterian argument is that competition reduces the expected pay-off from R&D and therefore reduce firm R&D. This prediction has triggered a number of theoretical papers which, in contrast to Schumpeter's view, have shown that increased competition stimulates innovation and R&D. For example, 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 *et al.* (2005) combine theories on competition and R&D showing that the positive impact of competition on R&D probably dominates when the level of competition is low while at a higher level of competition, additional increases in competition decrease firm R&D. That is, an inverse U-shaped form is predicted.

To the best of our knowledge, no paper has explicitly investigated the inverse U-shape proposition for the service sector. Examples of studies that have found a non-linear – inverse U-shaped form – between competition and R&D include e.g. Scott (1984), Levin *et al*. (1985) and, more recently, Aghion *et al*. (2005), Poldahl and

Tingvall (2006), Azkenazy *et al*. (2008) and Kilponen and Santavirta (2007) using UK, Swedish, French and Finnish firm-level data, respectively.

However, several gaps remain to be filled. First, existing studies have focused on the manufacturing sector leaving a question mark on the generality of the results. Second, improvements in the measurement of competition have come into play. In particular, the Boone (2008) and Boone *et. al.* (2007) *Price Elasticity* (PE) measure (focusing on the elasticity of output w.r.t. changes in input prices) has been shown to capture competition well. Third, as pointed out by e.g. Grünfeldt *et al*. (2006), it may be particularly problematic to use R&D as the only measure of efforts spent in innovative activities in the service sector. For example, the concept of ice-hotels is to be regarded as a service-sector innovation but the resources spent on developing the concept are most likely not found in firms' R&D figures. Hence, alternative response patterns should be taken into account.

Using detailed Swedish firm-level data, we apply the Boone PE-measure and the Herfindahl index to explore how innovation in the service sector responds to competition. In addition, we combine CIS survey-data on firms' innovative activity with detailed firm-level register data. This combination allows us to explore other response patterns than increasing/decreasing total R&D expenditures while simultaneously keeping track of firm performance and competition. Alternative responses include e.g. how innovative activities such as intramural R&D, extramural R&D, and firms' spending on acquiring external knowledge (education and training programs etc.) are affected by competition.

Competition may not only affect the amount of resources spent on innovative activities, it may also alter firms' incentives to collaborate with competitors in innovative activities. That is, competition may alter the incentive to form strategic alliances. The linked CIS innovation survey and firm-level register data allow us to empirically analyze these questions.

Our results point at an inverse U-shaped relation between competition and R&D. More precisely, with the exception of non-exporting firms, the Boone PE-measure and the Herfindahl index usually come up with an inverse U-shaped shape.

Using CIS innovation data to decompose innovation expenditures, we find intramural R&D and training to show an inverse U-shaped relation to competition while extramural R&D decreases with competition. Additional results show that as competition increases, there is not only a decrease in extramural R&D but also in the propensity for large firms to form strategic alliances with competitors. This behavior may be explained by the fact that the value of a marginal edge to the competitors goes up as competition becomes sharper.

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

2. Related literature

Over the years, studies on competition and innovation/R&D have shifted their focus from mainly industry-level studies toward firm-level studies. Despite the change in unit of observation, no consensus on the shape of the relation between competition and innovation/R&D has been reached. For example, Horowitz (1962), Mansfield (1968), and Crépon *et al*. (1998)[1] found competition to decrease R&D. Examples of studies that find a positive correlation between competition and R&D include Mukhopadhyay (1985), Geroski (1990), Blundell *et al*. (1995) and Nickell (1996).

Given that one want to wipe out fixed effects, one may apply a dynamic set-up using GMM based estimators and estimate fixed-effect models, or perform the analysis in first differences. In this tradition, Nickell (1996), Aghion *et al*. (2005) and Mulkay *et al*. (2000) apply one or a combination of these estimators on US, UK and French firms. Despite their methodological similarity, the results do not point in the same direction. Nickell finds that increased concentration increases productivity growth in UK-based companies, Aghion et al. (2005) find robust evidence of 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 no significant impact on French firms.

Another factor that may be crucial for the results is how competition is measured. A frequently used way of measuring competition is to quantify the degree of market concentration. Examples are the share of sales concentrated to the three or five largest firms in an industry (C3 and C5) and the Herfindahl index that also takes into account the distribution of market shares. Studies using market concentration as a measure of competition do not all come up with similar conclusion. For example, in a study of innovation in West German firms, Kraft (1989) finds that increased market concentration boosts firm R&D while Mansfield (1983) concludes that an increased rate of technological change is often associated with increased competition. Analyzing 4 378

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[1] 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.

innovations in the UK, Geroski (1990), finds no support for the hypothesis that competition is bad for innovation and growth.

Finally, the early literature focused mostly on a linear (or log-linear) relation between competition and R&D; some exceptions are Scott (1984) and Levin *et al*. (1985) who without explicitly seeking for an inverse U-shaped relation found some evidence of an inverse U-shaped relation between competition and R&D. Since Aghion *et al*. (2005), an inverted-U shaped relationship between competition and R&D has been detected by e.g. Azkenazy *et al*. (2008), Poldahl and Tingvall (2006) and Kilponen and Santavirta (2008). The Azkenazy *et al*. (2008) study includes data for all French businesses with at least 500 employees and covers both the service and the manufacturing sector. Azkenazy *et al*. (2008) do not separate the analysis among sectors and this precludes us from drawing any specific conclusions about the behavior of service-sector firms.

3. Theoretical background and variables

3.1 Theoretical background

The main prediction of the Aghion *et al*. (2005) model is an inverted U-shaped relation between competition and R&D. The intuition behind the positively sloping segment – the escape competition effect – is that the more neck-to-neck competition there is (small productivity differences across firms), the greater is the pay-off from an edge over the competitors. Hence, if competition is fierce, firms might escape competition by innovating. On the other hand, as predicted by the Schumpeterian model, profits will be limited at high levels of competition, thus making it hard to recover R&D expenditures. Hence, competition holds back R&D. Put together, these two contradicting forces give rise to an inverse U-shaped relationship between competition and R&D.

In addition to Aghion *et al*. (2005), Haruyama (2006) offers three additional reasons for an inverted U-shaped relation between competition and innovation.[2]

Finally, as pointed out by e.g. Hipp and Grupp (2005) and Tether (2007), the innovation process does not only concern R&D and this might be particularly true for the service sector where technology is rather embodied in knowledge than in machinery and equipment. Accordingly, one should go beyond intramural R&D when analyzing how competition affects service-sector firms' expenditures on innovative activities.

As noted in the IO literature, cooperation with a competitor in an R or D project (forming a strategic alliance) may be a way for the firm of escaping competition (Reinganum, 1989).[3] Therefore, we conclude with an analysis of how the propensity to participate in a strategic alliance is affected by competition.

Services differ from manufactured goods in some respects. First, services are typically produced and consumed in the same geographical location, i.e. there is a spatial or regional dimension involved. This means that the effects of competition on service firms' innovative activities will also be hampered by this spatial dimension. Second, in comparison to the manufacturing sector, knowledge generated in the service sector is often less connected to physical innovations. Hence, education, training and similar pro innovative activities should be more important in the service sector than in the manufacturing sector − thus motivating that efforts should be spent to shed light on these activities and not only on R&D expenditures per se.

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[2] Harauyma points at (i) the cumulative aspects of R&D, (ii) that firm's do not only conduct R&D and (iii) that components are often improved independently of each other but may interact with other components.

[3] There may be several motives behind forming a strategic alliance; suggestions highlighted in the literature include motives such as risk minimization, cost minimization, shortening of development

3.2 Variables

Our base-case measure used to proxy innovation is register data on firms' R&D expenditures covering all firms with at least 50 employees. CIS innovation surveys 2 through 5 allow us to decompose firms' innovation expenditures. To be precise, we decompose firms' expenditures on innovative activities to: (i) intramural R&D, (ii) extramural R&D and (iii) expenditures on achieving external knowledge (education, training etc). Finally, we have a dummy variable indicating whether a firm is engaged in an innovation project with a competitor (strategic alliance).

We apply two measures of competition that aim at capturing different aspects of competition. First, we have the Herfindahl index *(H)* – more competitors and/or more equally distributed market shares produce a lower value of the Herfindahl index, indicating increased competition. It should be borne in mind that, by construction, the Herfindahl index does not capture competition between domestic firms and firms located abroad. Therefore, the Herfindahl index is more appropriate for economies with a large domestic market than for small economies.[4] Second, we have the Boone price elasticity measure (PE).

The idea behind the PE-measure is that the elasticity of output is more sensitive to cost changes in more competitive industries. One advantage of the PE measure is that if firms change their way of conduct for some external reason and start to compete more intensively, resulting in firm exit, both the Herfindahl index and the price cost margin might signal decreased competition, while the PE-measure correctly picks up the change; for details, see Bone (2007). We estimate the PE-measure following Boone

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cycles, complementarities in resources and competition/market structure motives. For a survey, see e.g. Hagedoorn *et. al*. (2000), Dunning, (1997) and Teece (1992).

[4] 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).

(2008) and Boone *et al*. (2007) to derive the elasticity of profits with respect to marginal costs. The measure is generated by an OLS estimation of the following relation for each year and each 4-digit industry:

$$\ln(\pi_{ijt}) = \alpha_j + \beta_{jt} \ln(c_{ijt}) + d_t + \varepsilon_{ijt} \qquad \text{(eq. 1)}$$

where *i* is a firm-level identifier, *j* is an industry indicator and *t* indicates the time period. Variable profits, π, are calculated as value added less the total wage bill and marginal costs are approximated by average variable costs, *c*, which are defined as the total wage bill plus the costs of variable inputs (sales less value added), divided by sales. The estimated profit elasticity, β_{jt}, is used as our time-varying industry measure of product market competition.

An issue that is often neglected in the literature on globalization and the measurement of competition is that the market is often located in the home country, while the R&D activity may be concentrated to one country. Hence, competition in foreign markets may affect the amount of R&D performed at home. Therefore, if firms are unable to segment markets, the Boone PE-measure might be preferable to the Herfindahl index.

A firm does not rely on internally generated technology only, technology generated outside the firm is also important. The stock of firm-specific knowledge may come from different sources that are internal or external to the firm, such as intramural R&D, learning by doing and knowledge spillovers. Knowledge spillovers may be domestic or international following e.g. input-output links and trade. In this context, the importance of learning through export becomes clear. An argument put forward for export to promote R&D is that export enhances the absorption of outside knowledge.

Hence, export reduces the cost of overcoming the next generation of knowledge and therefore increases the possibility of successful R&D.[5] We incorporate trade-related spillovers by adding firms' *export ratio* into the analysis.[6]

Knowledge and technology may not only stem from foreign identities. A firm that is distant from the technology frontier may have more outside information to absorb than the leading-edge firm. Following e.g. Griffith *et al*. (2000) and Aghion *et al*. (2005), we capture this type of spillover using a *technology gap* parameter measuring the distance to the technological leader in the industry.

One characteristic of the Aghion *et al*. (2005) model is that it predicts the "escape competition effect" to be the strongest in leveled industries (where firms compete *neck-to-neck)*.[7] Following Poldahl and Tingvall (2006), we test this hypothesis by including an interaction between the intra-industry technology gap and the degree of competition.

The maybe most well-analyzed variable causing firm R&D is *firm size*. Decades of empirical research on the relationship between firm size and R&D have established a consensus view of an elasticity of R&D with respect to firm size close to unity. We control for firm size throughout all estimations.

In the literature on embodied technological change (Stoneman, 1983), technological progress is propelled by investment in new machinery, thus pointing at a link between

[5] For the role of trade as a carrier of knowledge spillovers, see e.g. Griliches, 1992; Stoneman 1995, Coe and Helpman 1995 and Keller 2000.
[6] Griliches (1992) points at substantive and significant spillovers associated with trade. In addition, in line with Griliches (1992), Wolfgang Keller (see e.g. Keller 1997, 2000, 2002a, 2002b) finds evidence of trade-related technology spillovers.
[7] Leveled industries are industries characterized by small differences between firms in terms of productivity. Within these industries, competition among firms is high and a small step outside the current production frontier may result in large gains. This will trigger firms to steal market shares from their competitors and will hence stimulate their R&D activities. Firms will escape competition by innovating; see Aghion *et al.* (2005).

capital and R&D. Hence, to single out the impact of competition on firm innovation and R&D, we control for capital intensity (*K/L*).

In the Aghion *et al*. (2005) model, labor is homogenous − all workers are equally well suited for R&D − and each firm chooses the allocation of labor to R&D that maximizes the current value of profits. However, it might be plausible to argue that R&D is dependent on the skill composition of the labor force. To control for firms' skill composition, we include the share of skilled workers (workers with at least post-secondary education). An econometric issue is the direction of causality; do firms' R&D expenditures depend on their human capital abundance or vice versa? We tackle possible endogeneity using an instrumental variable approach and the full model specification takes the form[8]:

$$
\begin{aligned}
\ln(\mathrm{R\ \&\ D})_{\mathrm{ijt}} &= \alpha_0 + \alpha_{\mathrm{ij}} + \alpha_{\mathrm{t}} + \beta_1(\mathrm{competition})_{\mathrm{jt}} + \beta_2(\mathrm{Skillint})_{\mathrm{ijt}} \\
&+ \beta_3(\mathrm{A-gap})_{ijt-s} + \beta_4(\mathrm{neckness})_{ijt-s} + \beta_5(\mathrm{export})_{\mathrm{ijt}} \qquad \text{(eq.2)} \\
&+ \beta_6\ln(\mathrm{Size})_{\mathrm{ijt}} + \beta_7\ln(\mathrm{K/L})_{\mathrm{ijt}} + \varepsilon_{\mathrm{ijt}} \quad ; \quad \varepsilon_{\mathrm{ijt}} \sim \mathrm{iid}(0, \sigma_\varepsilon^2)
\end{aligned}
$$

where R&D is expenditures on R&D in firm *i* in industry *j* at time *t, skillint* is the share of skilled workers, *A-gap* is the distance to the industry technological leader, *neckness* is the degree of neck-to-neckness, *export* is firm export ratio, *Size* is firm size measured as the number of employees, *K/L* is capital intensity, competition is captured by the Herfindahl index and the Boone PE-measure and ε is the classical error term.

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

3.3 Data and variable construction

Data stems from Statistics Sweden (SCB) and covers the years 1997 through 2005. Four different databases have been merged: (i) the Financial Statistics (FS) Database, (ii) the R&D survey and (iii) the Regional Labor Market Statistics Database (Rams). These three register databases include all manufacturing and service-sector firms and with a slight abuse of notation, we label the merged outcome of (i) through (iii) Financial Statistics, or only "FS". FS data does not only provide us with information on the profit and loss account of the firm, and its associated variables such as gross production and value added, employment, capital stock, purchases of other inputs, R&D expenditure etc., but also with information on workers' level of education, gender and age.

We have register information on R&D activities of firms from the FS Database and the bi-annual R&D survey.[9] Both these sources have their advantages and shortcomings. The advantage of the R&D data from the FS Database is that it has been collected on a yearly basis during the years 1986-2005 and covers all firms with at least 50 employees.[10] The bi-annual R&D data from the R&D survey is collected for firms that reported R&D expenditures of no less than 2 million SEK in the FS questionnaire. In the R&D survey, firms should give the exact amount.

In addition to these three register based data-sets we have additional information on firms' innovation efforts from the "Innovation Activity in Swedish Enterprises Surveys" (CIS). The CIS data used here is drawn from the CIS 2-survey

[9] Data on the R&D variable stems from the Financial Statistics (FS) and covers 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. The respondents are asked to give an exact figure for R&D expenditure or answer in an interval scale. R&D is not evenly distributed across industries.

[10] In the FS register, the firm may give an answer within specific intervals of SEK; 1-249 000, 250 000-999 000, 1-4.9 million, 5-9.9 million and then 10 million or more. If the yearly R&D expenditures exceed 10 million SEK, the firms shall specify the exact amount.

1994-1996, the CIS 3-survey 1998-2000, the CIS 4-survey 2002-2004 and the CIS 5-survey 2004-2006.

Table 1. Descriptive statistics, firm averages for service-sector firms, 1997-2005

	Exporters L > 50	Non-exp. L > 50	CIS 10<L<50	CIS L > 50
R&D	3975	1363	n.a.	28503
(R&D/sales)*100	1.61	0.33	n.a.	1.97
Intramural R&D			59	314
Extramural R&D			20	89
Training/firm			26	95
Size (L)	141	109	19	213
Share skilled labor	0.34	0.22	0.24	0.25
ln(K/L)	4.81	4.74	5.1	5.4
Export ratio	0.18	0	0.01	0.28
Technology gap	13	14.3	14.06	12.2
PE-measure	-3.84	-3.78	-3.95	-4.54
Herfindahl index	704	641	876	1449
Strategic alliance y/n	n.a.	n.a.	0.03	0.07
Obs.	10 033	18 434	4 848	3 099

Note: Observations in columns 1-2 stem from the financial statistics (FS), including all service firms. The figures in columns 3-4 stem from firms observed in the CIS innovation survey. Due to the sampling of innovative firms into the innovation survey, the observed R&D-intensity is greater in the survey than in the whole population.

From the four CIS Surveys, we have extracted information on firms' expenditures on: intramural R&D, extramural R&D, external knowledge (education, training etc.) and a dummy variable indicating whether the firm co-operates with a competitor in an innovation project.

The respondent rates for CIS surveys are quite high. The overall response rate in the CIS 2-survey was 75% and 70% in the manufacturing and service sector, respectively.. The response rate has remained high in the following surveys, especially for our main variables.

We calculate capital stocks using an extended PI-method. TFP is measured using the Törnqvist index number approach and a detailed variable description is given in the Appendix.

Summary statistics of the variables are given in Table 1 and description by industry in Table A4. As seen in Table A4, the variation in R&D across industries is larger than the variation in e.g. firm size, export ratio and competition and from Table 1 we find that the export intensity of small firms (included in the CIS survey) is around 1 percent while the export intensity of larger firms is as high as 28 percent. In all, this points at a substantial heterogeneity across firms and industries and a need for analyzing data from different perspectives.

4. RESULTS

4.1. Basic models

As noted above, R&D expenditures in FS and the Research Statistics are truncated from below; accordingly in Table 2, we present results from the Tobit regression estimated on all firms with at least 50 employees.

Columns 1-2 show results using a basic set-up that we expand in columns 3-4 to also include measures of export, catching up (technology gap) and neck-to-neckness competition.

The control variables match our prior expectations. The effect of human capital intensity (workers with at least tertiary education) and physical capital per worker is both positive and highly significant.[11] A coefficient for firm size above unity indicates that large firms, on average, are more R&D intensive than smaller ones (indicating increasing returns in R&D).

In columns 3-4, we augment the model with export, catching up and a variable capturing neck-to-neckness competition. The technology gap variable allows us to analyze catching up and domestic intra-industry spillovers. Our results suggest that the further away a firm is from the technological leader, the less it spends on R&D while export is positively related to R&D activity. No evidence of an impact of neck-to-neckness on firm R&D is found.[12]

Table 2. Competition and R&D, Tobit estimation

	1. Basic	2. Basic	3. Large	4. Large
$(-1)*Herf_{(t-1)}$	-0.004 (-11.77)***		-0.0035 (-10.46)***	
$(-1)*Herf^2_{(t-1)}$	-7.4e-07 (-8.79)***		-6.3e-07 (-7.75)***	
$(-1)*Boone_{(t-1)}$		0.0973 (2.39)***		0.1326 (3.15)***
$(-1)*Boone^2_{(t-1)}$		-0.0002 (-0.10)		-0.0012 (-0.87)
$\ln(size)_{(t)}$	1.3995 (18.42)	1.4005 (17.08)***	1.3765 (18.34)***	1.3501 (16.69)***
Skilled labor $share_{(t)}$	37.896 (34.57)***	40.106 (35.06)***	33.557 (31.32)***	35.246 (31.61)***
Capital $intensity_{(t)}$	0.6176 (12.70)***	0.7132 (14.16)***	0.5472 (11.30)***	0.6370 (12.75)***
Export $ratio_{(t)}$			5.8118 (19.64)***	6.1748 (20.16)***
Tech $Gap_{(t-1)}$			-0.0215 (-2.02)**	-0.0297 (-2.50)***
Neck-to-$neckness_{(t-1)}$			8.4e-18 (0.13)	3.0e-16 (0.14)
Period dum	yes	Yes	Yes	yes
Industry dum	yes	Yes	Yes	yes
Pseudo R^2	0.14	0.14	0.16	0.16
Obs	25 021	24 744	24 408	24 131
F-test Comp [(A)]	0.000	0.000	0.000	0.000

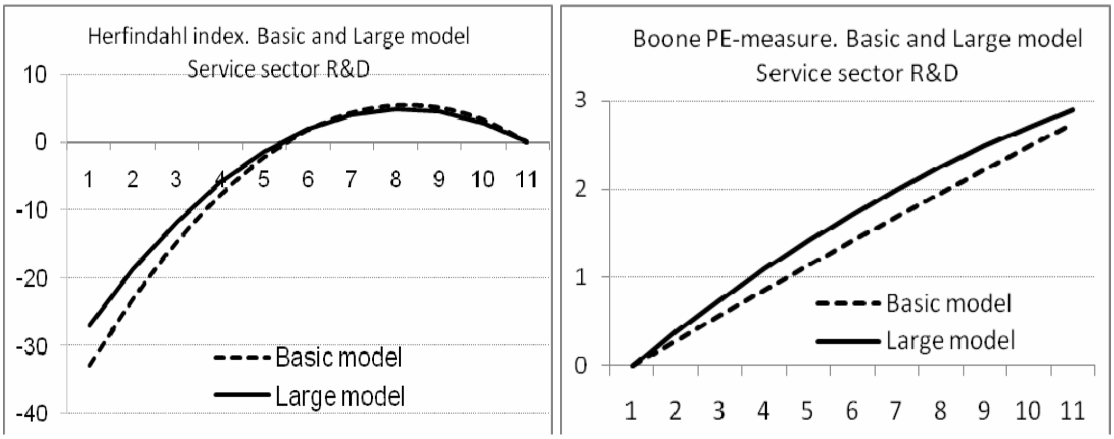
*, **, *** indicate significance at the 10, 5 and 1 percent level, respectively. t-value within parenthesis ().[(A)] F-test competition variables.

To visualize the relation between competition and R&D, we depict the estimated relation of the empirical range of the competition variables. To simplify the

[11] As discussed above, due to endogeneity, we instrument the human capital variable and the instruments are lagged values of the skill variable, average wage, ownership and fixed effects.

interpretation, the competition variables are multiplied by minus one (-1), implying that higher values are interpreted as higher levels of competition.

Figure 1. Curvature of estimated relation between competition and R&D



Note: All curves in Figure 1 are significant at the one-percent level. The competition variables are multiplied by minus one (-1) implying that higher values are interpreted as higher levels of competition. The complete set of regression results are found in the Appendix.

Figure 1 shows the results drawn from estimations in Table 2. The Herfindahl index suggests a clear inverse U-shaped relation between competition and R&D. For the Boone PE-measure, within the interval for which the price elasticity is observed, the negative second-order term does not overcome the positive term and no downward sloping Schumpeterian segment is achieved. In addition, appending the neck-to-neckness variable, the firm export ratio and the catching up variable does not alter the observed curvature to any considerable extent.

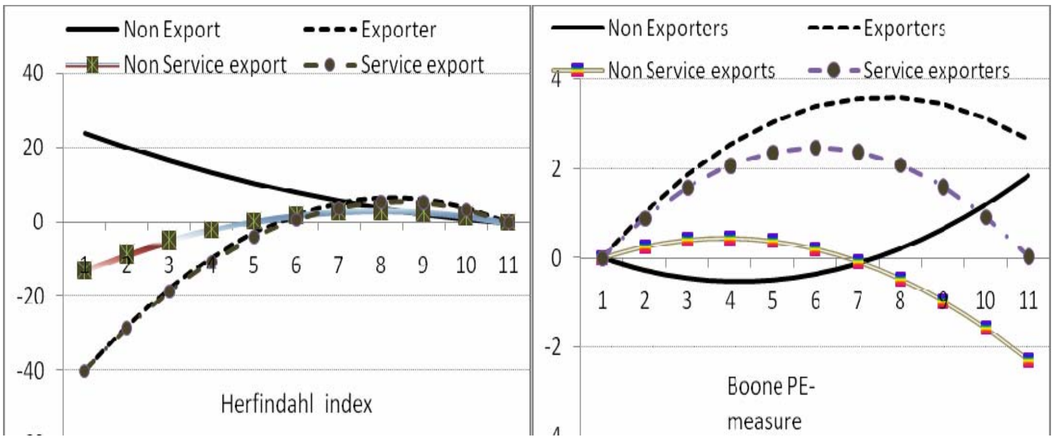
4.2. Exporters and non-exporters

One characteristic of services is that they are often produced and consumed simultaneously (at one geographic point). Hence, competition has a geographic bound.

[12] In models with a Herfindahl index, we interact the A-gap with the Herfindahl index; similarly we

At the same time, more services are becoming tradable. Service firms producing tradable output will – like many manufacturing firms – compete with firms that may be located at a distance. Hence, there are reasons to expect firms producing tradables to be more exposed to competition than service firms in the non-tradable segment, and since their situation is similar to that of manufacturing firms, they also behave similarly to manufacturing firms. Therefore, we split the sample into non-exporting and exporting service firms, as well as the sub-groups service exporters and non-service exporters. Table 1 indicates that the difference in competition faced by exporters and non-exporters is relatively small. However, even if the estimated level of competition does not differ to any considerable extent, the response pattern may. Results from the Tobit analysis are shown in Figure 2.

Figure 2 . Exporting and non-exporting service firms.



Note: In the left-hand panel (Herfindahl index), an F-test indicates that all curve types but non-exporters are significant at the one-percent significance level. In the right-hand panel (Boone PE-measure), all curves are significant at the one-percent level. Competition variables are multiplied by minus one (-1), implying that higher values are interpreted as higher levels of competition. The complete set of regression results is found in the Appendix.

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interact the A-gap with Boone-PE in estimations where the Boone-PE measure is used.

Figure 2 verifies the basic findings from Figure 1, namely that with the exception of non-exporters, there tends to be an inverse U-shaped relation between competition and R&D. To be precise, for the Herfindahl index, the only curve that is not inverse U-shaped (and the only non-significant curve) is found for non-exporting service firms. Looking at the Boone PE-measure, all curves are significant at the one-percent level and everyone but non-exporters shows an inverse U-shaped pattern. Hence, the results for Swedish service firms indicate an inverse U-shaped relation which is in line with the results found for Swedish manufacturing firms; for details on manufacturing firms see Poldahl and Tingvall (2006).

4.3. Decomposition of innovative activities

It is plausible to argue that competition does not only affect intramural R&D but also outsourced (extramural) R&D and other innovative activities. Using data from four CIS surveys, we construct three categories of innovative activity: expenditures on intramural (local) R&D, expenditures on extramural (outsourced) R&D and expenditures on achieving external knowledge (education, training etc.).

About two thirds of the firms included in the CIS surveys report no expenditures on innovative activities. This is most likely an exaggeration. Arguments for firms to underreport expenditures on innovative activities include (i) small firms with no separate R&D department are probably more likely to report zeros, (ii) expenditures on innovative activities are sensitive and firms might be reluctant to disclose such information and (iii) Laursen (2008) argues that the CIS survey figures on innovation by design have a (mild) censoring and therefore, advocates Tobit estimations. Therefore, our econometric analysis is principally the same as before, measures of competition as well as the control variables are defined correspondingly using the FS data, while our new measures of innovations stem from the CIS-surveys.[13] Due to data limitations and in order to economize on observations, we estimate Tobit regressions using the basic model specification. Since firms with less than 50 employees are included in the CIS surveys, we define the competition measures for small and large firms, respectively. The limited size of the CIS surveys, the number of possible years to use and the matching of data leave us with a much smaller dataset (2 200 *vs*. 47 000 obs.).[14] To adjust for the duration of the CIS surveys and possible lags between competition and innovative behavior, we lag CIS data one year when matching it on FS-data.

Results on how various innovative activities respond to competition are depicted in Figure 3 below.[15] We find support for the hypothesis of an inverted U-shaped relation between competition and both intramural R&D and training (acquiring external knowledge). However, no inverse U-shaped pattern is detected for extramural R&D. As competition goes up, if anything, there is a tendency for large firms to shift R&D from extramural to intramural R&D. The shift from extramural to intramural R&D is shown in Table A3 columns 3-4 where we regress the allocation of intramural/extramural R&D on competition. The clearest result is found for the Boone PE-measure and large firms. For small firms, we do not find any significant reallocation which is probably due to a low degree of extramural R&D activity in small firms (with 49 employees at most).

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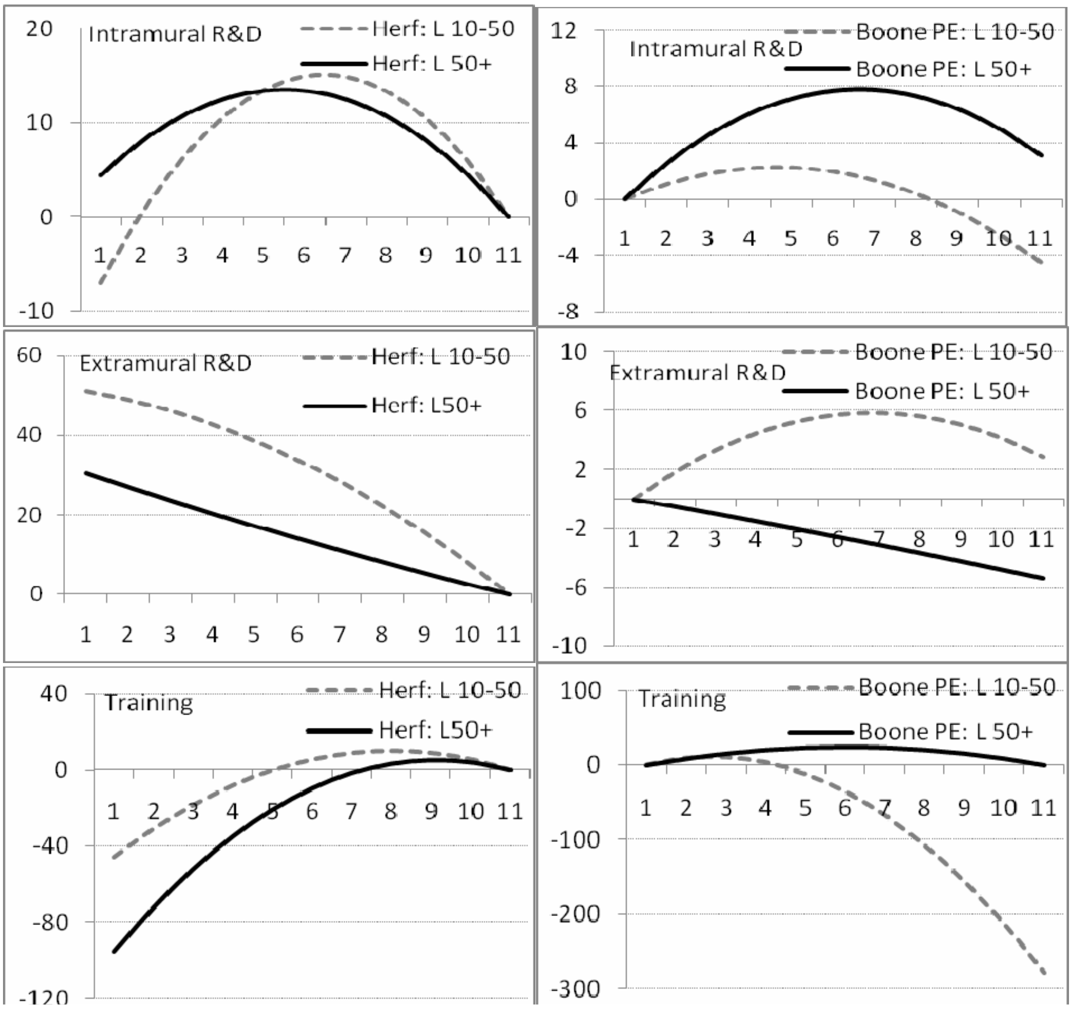
[13] As a robustness test, we re-estimated Col. 1 (with the most significant competition variables) in Table A2 using XTGLS. The results are close to the Tobit estimates. For details, see the notes in Table A2.

[14] The previous analysis was only based on variables and firms with more than 50 employees, whereas from now on, the analysis and the variable construction are based on variables for firms with more than 10 employees.

[15] Results from the regression analysis are given in Table A3 in the Appendix.

Comparing results from the Boone PE-measure and the Herfindahl index, we find the Herfindahl index to generally yield significant results for different innovative activities while the Bone PE-measure is mostly insignificant (except for training). However, for intramural R&D, the curvature from the two measures is relatively similar.

Figure 3 . Decomposition of innovative activities.



Note: In the left-hand (Herfindahl index) panel, the F-test indicates all curves but training to be significant at the ten-percent significance level. In the right-hand panel (Boone PE-measure), the F-test indicates that only training for large firms is significant at the ten-percent significance level. Competition variables are multiplied by minus one (-1), implying that higher values are interpreted as higher levels of competition. The complete set of regression results is found in the Appendix.

Finally, from a policy perspective, it is interesting to note that the downward sloping segment where increased competition contracts innovative expenditures only occurs at relatively high levels of competition. Hence, the risk that fighting monopoly and lack of competition will decrease innovative activities is relatively small.

4.4 Extension: Competition and strategic alliances

To broaden the picture of firm response to competition, we finally analyze whether competition affects firms' incentives to cooperate in innovative activities with competitors, here labeled strategic alliances. As noted above, there are several motives for firms to form a strategic alliance and competition may play a role in that decision. The results given in Table A3 are somewhat inconclusive. Combining results from the Herfindahl index and the Boone PE-measure points at, if anything, competition tending to increase the probability of small firms forming a strategic alliance with a competitor, while the opposite is true for larger firms. That is, increasing competition tends to decrease (increase) the incentive for large (small) firms to participate in a strategic alliance.

As pointed out by Aghion *et al*. (2005), as competition increases, it becomes increasingly important to remain at the technology frontier – a task which is facilitated by cooperation with a competitor. In addition, for small firms it may be difficult to host research and development project by themselves. This is a possible explanation as to why small firms tend to seek more strategic alliances as competition goes up. However, for larger firms with a greater capacity to host innovative activities, the playing field is somewhat different. On the one hand, a strategic alliance decreases the risk with an innovation project but, at the same time, decreases the expected pay off from R&D expenditures. Since large firms typically have a larger potential to host innovation projects and the pay off increases with competition, it may be tactically correct for larger firms to behave differently than smaller firms.[16]

5. SUMMARY AND CONCLUSIONS

The central prediction of the Aghion *et al.* (2005) model is an inverted U-shaped relation between innovation and competition. The model is built on the assumption of a product market and fits manufacturing firms well. A number of empirical studies covering the manufacturing sector indicate that an inverse U-shaped relation between competition and R&D can be found. However, innovation includes strategies over a wide set of parameters such as technological choice of machinery and investments, education of the labor force, offshoring of R&D etc; hence, not only intramural R&D is affected by competition. In addition, innovation in the service sector is often linked to disembodied technological change and non-technological innovative processes such as organizational arrangements etc. Altogether, evidence points at R&D being less dominant as a major indicator of innovation for the service sector than for the manufacturing sector. Therefore, it is of particular interest to analyze how the inverse U-shaped relation stands up in an empirical test on the service sector.

Our results point at an inverse U-shaped relation between competition and R&D in the service sector. However, some firms deviate from the general picture. The connection between R&D and competition is somewhat weaker in non-exporting firms. For those firms, we find no inverse U-shaped relation to competition. Hence, measures

[16] For an introduction to the pay offs and motives for R&D, see e.g. Cohen and Levinthal (1989).

of competition signal that R&D in non-exporting service firms reacts different to competition than R&D in exporting firms.[17]

To broaden the picture of firms' reaction patterns, we analyze alternative responses to competition from different types of innovative activities. More specifically, we separate innovative activities into expenditures on intramural R&D, expenditures on extramural R&D and expenditures on the acquisition of external knowledge (education, training etc.). We find evidence of an inverted U relation not only for intramural R&D but also for training and acquisition of external knowledge. For service-sector firms, technology is often more bounded to knowledge and soft technology than for manufacturing firms. Therefore, education and training might be especially important for service-sector firms. Thus, it is interesting to note that intramural R&D and education and training respond to competition in a similar manner. However, this pattern is not found for extramural R&D. As competition goes up, there is a tendency to reallocate from extramural to intramural R&D. This can be taken as an indication of either a home preference for local R&D or as an indication of Sweden being a relatively competitive country as a location for R&D.

Finally, we analyze how the propensity to participate in strategic alliances is affected by competition. We find that small and large firms behave differently. There is a tendency for small firms to seek more strategic alliances as competition goes up, while we see the opposite for large firms. These contradicting observations may be explained by small firms' limited capacity to host large innovation projects by themselves when – at the same time – increasing competition makes it crucial to be at the technological frontier. For large firms, on the other hand, which have a larger internal capacity to

[17] The Boone PE-measure indicates that the more fierce competition non-exporters face, the more do they spend on R&D.

handle innovation projects, the pay off of an incremental edge to competitors increases as competition becomes more fierce (neck-to-neckness), giving an argument for not sharing new discoveries with competitors.

At a general level, we note that the inverse U-shape found suggests that the risk of decreased R&D and innovation as a consequence of fighting low competition is probably limited. To be precise, in low competition markets, R&D activity most likely increases with competition while in markets where competition is already very fierce, a further increase in competition may reduce the incentives to innovate.

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Appendix

Variables

1. R&D: Total Research and Development expenditures[18] in 1990 constant prices.

Source: Statistics Sweden/Research Statistics.

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

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

3. Export ratio: $\text{Export}_{it}/\text{sales}_{it}$.

4. TFP: Total factor productivity (measured by means of Törnqvist index).

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.

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

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

8. Skillint: Share of employees with post secondary education.

Source: Statistics Sweden/Regional Labor Statistics.

9. Intramural R&D. Source: Statistics Sweden /CIS survey 2 through 5.

10. Extramural R&D. Source: Statistics Sweden /CIS survey 2 through 5.

[18] R&D is an activity which takes place on a systematic basis 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).

11. Expenditure on external knowledge/training. Source: Statistics Sweden /CIS survey 2 through 6.

12. Collaboration in innovative activities (yes/no) with a competitor. Source: Statistics Sweden /CIS survey 2 through 6.

Table A1. Competition and R&D, Tobit estimation, Exporters and non-exporters

Variable	1. No exp tot exp	2. No exp / tot exp	3. No exp / serv exp	4. No exp / serv exp
(-1)*Herf non exporters$_{(t-1)}$	-0.0008 (-1.86)		-0.0021 (-4.93)	
(-1)*Herf^2 non exporters$_{(t-1)}$	-1.6e-07 (-1.62)		-3.4e-07 (-3.42)	
(-1)*Herf exporters$_{(t-1)}$	-0.0048 (-11.56)		-0.0043 (-9.91)	
(-1)*Herf^2 exporters$_{(t-1)}$	-8.8e-07 (-8.20)		-8.3e-07 (-7.39)	
(-1)*Boone non exporters$_{(t-1)}$		-0.1098 (-2.51)		0.1040 (2.40)
(-1)*Boone^2 non exporters$_{(t-1)}$		0.0057 (3.35)		-0.0006 (-0.40)
(-1)*Boone exporters$_{(t-1)}$		0.3638 (8.66)		0.3282 (4.87)
(-1)*Boone^2 exporters$_{(t-1)}$		-0.0092 (-4.69)		-0.0109 (-2.58)
ln(size)$_{(t)}$	1.3201 (17.49)	1.2630 (15.60)	1.3425 (17.82)	1.3017 (16.00)
Skilled labor share$_{(t)}$	33.098 (30.78)	34.037 (30.64)	32.666 (30.29)	33.740 (29.82)
Capital intensity$_{(t)}$	0.5280 (10.82)	0.5915 (11.84)	0.5259 (10.78)	0.6188 (12.37)
Export ratio$_{(t)}$	5.3224 (17.72)	5.4672 (17.65)	5.7736 (19.40)	6.0824 (19.80)
Tech Gap$_{(t-1)}$	-0.0170 (-1.54)	-0.01175 (-1.02)	-0.0237 (-2.17)	-0.0242 (-2.13)
Neck-to-neckness$_{(t-1)}$	1.9e-16 (0.96)	-4.3e-15 (-1.76)	1.3e-16 (0.66)	-3.0e-15 (-1.25)
Period dum.	yes	yes	yes	yes
Industry dum.	yes	yes	yes	yes
Pseudo R^2	0.16	0.16	0.16	0.16
Obs	24 212	23 929	24 263	23 980
F-test no exp. [(A)]	0.179	0.003	0.000	0.000
F-test exp. [(B)]	0.000	0.000	0.000	0.000

*, **, *** indicate significance at the 10, 5 and 1 percent level, respectively. t-value within parenthesis ().
[(A)] F-test competition variables, non-exporters. [(B)] F-test competition variables, exporters.

Table A2. Competition and innovation activity composition. CIS survey data. Tobit analysis.

Variable	1.intra-mural R&D	2.intra-mural R&D	3.extra-mural R&D	4.extra-mural R&D	5. Edu. etc.	6. Edu. etc.
(-1)*$Herf_{(t-1)}$ (size 10-50)	-0.0095 (-3.40)		-0.0120 (-2.92)		-0.0096 (-1.54)	
(-1)*$Herf^2_{(t-1)}$ (size 10-50)	-1.5e-06 (-2.20)		-6.7e-07 (-0.77)		-2.3e-06 (-1.07)	
(-1)*$Herf_{(t-1)}$ (size 50+)	-0.0070 (-2.23(		-0.0037 (-0.74)		-0.0081 (-1.01)	
(-1)*$Herf^2_{(t-1)}$ (size 50+)	-9.1e-07 (-1.27)		9.2e-08 (0.08)		-3.1e-06 (-1.17)	
(-1)*$Boone_{(t-1)}$ (size 10-50)		0.6225 (0.58)		0.9946 (0.46)		6.8527 (1.92)
(-1)*$Boone^2_{(t-1)}$ (size 10-50)		-0.0425 (-0.45)		-0.1145 (-0.47)		-1.0372 (-1.94)
(-1)*$Boone_{(t-1)}$ (size 50+)		1.3831 (1.39)		-0.2435 (-0.18)		4.8260 (1.97)
(-1)*$Boone^2_{(t-1)}$ (size 50+)		-0.0614 (-0.83)		-0.0012 (-0.02)		-0.2406 (-1.04)
ln(size) $_{(t)}$	3.1467 (6.61)	2.3986 (3.27)	4.1413 (5.09)	4.0374 (3.14)	3.7938 (4.77)	3.0596 (2.45)
Skilled labor $share_{(t)}$	81.357 (9.59)	91.443 (10.79)	58.840 (4.02)	75.179 (5.08)	37.432 (2.72)	46.847 (3.51)
Capital $intensity_{(t)}$	1.3215 (2.94)	1.6730 (3.72)	2.9612 (3.71)	3.4716 (4.27)	0.2119 (0.29)	0.4459 (0.61)
Period dum.	yes	yes	yes	yes	yes	yes
Industry dum.	yes	yes	yes	yes	yes	yes
Pseudo R^2	0.05	0.05	0.03	0.02	0.02	0.02
Obs	2 274	2 263	2 274	2 263	2 057	2 049
F-test < 50 [(A)]	0.000	0.847	0.000	0.891	0.209	0.144
F-test > 50 [(B)]	0.010	0.316	0.093	0.946	0.493	0.028

*, **, *** indicate significance at the 10, 5 and 1 percent level, respectively. t-value within parenthesis ().
[(A)] F-test competition variables, 10-49 employees. [(B)] F-test competition variables, 50+ employees. [(C)] Expenditures in external knowledge excluding investments in machinery (embodied technical change), i.e., training and education are the main components.

[(B)] As a robustness test, we re-estimated Col. 1 (with the most significant competition variables) by way of XTGLS – ignoring self censoring. The estimated coefficients for the Herfindahl index changed as follows; (-0.009 →-0.005; -1.5e-06→-8.9e-07; -0.007→-0.005; -9.1e-07→-7.8e-07). In addition, using XTGLS, the significance of coefficients increased to about -40 for the linear terms and approx. -13 for the second-order terms. Hence, the results are robust with respect to the choice of estimator.

Table A3. Cols 1-2: Competition and the probability of strategic alliances with competitors. Cols 3-4: Share intramural/extramural R&D and competition.

Variable	1. Logit [A] R&D coop	2. Logit [A] R&D coop	3.Tobit [B] local R&D	4. Tobit [B] local R&D
(-1)*Herf (size 10-50)	7.8e-05 (0.47)		12.7113 (0.98)	
(-1)*Herf (size 50+)	-0.0003 (-2.05)		1.3989 (0.09)	
(-1)*Boone (size 10-50)		0.1901 (2.79)		-2772 (-0.28)
(-1)*Boone (size 50+)		0.0581 (1.30)		31234 (4.12)
ln(size)	0.1602 (2.68)	0.2937 (3.78)	-4137 (-0.57)	-33523 (-3.23)
Skilled labor share	3.8410 (3.39)	4.4568 (3.93)	-62182 (-0.44)	-52112 (-0.39)
Capital intensity	0.1378 (2.34)	0.1326 (2.22)	6092 (0.77)	5328 (0.70)
Period dum.	yes	yes	yes	yes
Industry dum.	yes	yes	yes	yes
Pseudo R^2	0.10	0.10	0.002	0.006
Obs	2 141	2 127	262	262

*, **, *** indicate significance at the 10, 5 and 1 percent level, respectively. t-value within parenthesis ().
[A] Model 1-4 analyze how competition affects the probability that a firm has tactic innovation related cooperation with one or more competitors.
[B] Models 5-6 analyze how the share of intramural/extramural R&D is affected by competition-test competition variables.

Table A4. Descriptive statistics, firm averages, by industry, 1997-2005.

		CIS survey data			*Financial statistics, register data*					
Ind. Code	**Industry**	**Intramural R&D**	**Extramural R&D**	**Training**	**Firm size (L)**	**(R&D/sales) *100**	**R&D**	**Export ratio**	**PE-measure**	**Herfindahl index**
50	Retail and petrol	12189	163	n.a	109	0.38	1099	0.02	-3.78	305
51	Retail, vehicles	146	109	87	112	3.89	2525	0.10	-4.86	733
52	Retail, personal articles	n.a	n.a	n.a	127	0.10	1080	0.02	-4.89	865
55	Hotel	n.a	n.a	n.a	105	0.04	1057	0.03	-4.51	543
60	On land transportation	33	30	13	104	0.10	1100	0.02	-3.45	389
61	Sea based transportation	32	39	13	176	0.02	1148	0.21	-1.90	710
62	Air based transportation	38	0	2	209	0.73	1218	0.11	-5.82	4890
63	Storage and reloading	284	62	102	143	0.36	1288	0.10	-3.67	1036
64	Post, TV and Radio	359	481	429	257	8.23	2886	0.05	-4.43	2 870
65	Capital services	n.a	n.a	n.a	138	n.a	n.a	n.a	n.a	5 733
66	Insurances	n.a	n.a	n.a	96	n.a	n.a	n.a	n.a	7 688

Note: Observations in column 1-3 stem from CIS surveys. Figures in the right-hand panel stem from the Financial Statistics (FS) including all service firms with at least 50 employees.

Total factor productivity

Jorgenson and Griliches (1967) emphasized the importance of disaggregating the data on capital and labor. Gunnarsson and Mellander (1999) provide evidence on the importance of using disaggregated data when constructing a productivity measurement. We assume that the deflated sales value, *Y*, is produced using four factors of production; capital *K*, skilled labor *S*, unskilled labor *U*, and intermediate goods *M*. We assume a general production function

$$Y_{it} = A_{it}F(K_{it}, S_{it}, U_{it}, M_{it})$$

where Y_{it} is a Hicks neutral efficiency parameter measuring total factor productivity. As a first step in constructing a total factor productivity index, a functional form must be chosen. The Cobb-Douglas production function assumes all inputs to be substitutes, whereas the Translog allows for complementarity between inputs. We use the Divisia Törnqvist index in order to calculate changes in the input mix (a non parametric approach).[19] This index corresponds to a Translog production function. We calculate TFP as the ratio of deflated sales value to an index of input volumes (a Törnqvist quantity index of inputs).

$$TFP_t = \frac{Y_t}{f(X_{1t},\ldots,X_{nt})}$$

or, put differently,

$$\ln TFP_t = \ln Y_t - \ln X_t$$

similarly, growth in TFP:

$$\Delta \ln TFP_t = \Delta \ln Y_t - \Delta \ln X_t .$$

An important assumption in the calculations is that time is continuous. The majority of economic data is not continuous, however, and therefore a discrete approximation is often used, e.g. the Divisia index. Jorgenson and Griliches (1967) suggested a Törnqvist discrete-time approximation to the Divisia index. In the Törnqvist (1936) index, the weights used to aggregate the inputs are simply arithmetic averages of the corresponding cost shares in periods *t-1* and *t*, i.e. the average cost share

$$\varpi_{it} = \frac{1}{2}\left(\frac{P_{i,t-1}X_{i,t-1}}{\sum_{K=1}^{n} P_{k,t-1}X_{k,t-1}} + \frac{P_{i,t}X_{i,t}}{\sum_{K=1}^{n} P_{k,t}X_{k,t}} \right).$$

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[19] This index fulfills important properties such as invariance and independence; see e.g., Diewert (1976, 1978).

Regarding prices for capital, we compute rental prices according to Harper Berndt and Wood (1989)

$$P_{K,t} = P_{I,t-1}\left[r_t + \bar{\delta}_K + (\bar{\delta}_K - 1)\frac{P_{I,t-1}}{P_{I,t-2}} \right]$$

where $P_{K,t}$ is the rental price for capital, $P_{i,t-1}$ is the appropriate investment price index, r is the nominal long-term interest rate and $\bar{\delta}_K$ is the average rate of depreciation. The yearly depreciation rates, retrieved by the Statistics Sweden "National Accounts", are 18% for machinery and 3.18% for buildings.

The Gelos and Isgut (2001) method for calculating capital stocks

Gelos and Isgut (2001) suggest that the conventional PI method can be improved through the following two-step calculations:

Step 1: $K_t^1 = (1-\delta)Max(K_t^1 - 1, BF_{t-1}) + I_t - S_t$

where $K^1{}_t$ is the net capital stock at time t calculated in step 1, BF_{t-1} is the book value in t-1, I is gross investments and S capital disposal (calculated by comparing gross and net investments). The initial value on capital is based on the book value reported in the first year where the firm is observed in the dataset. The maximizing routine guarantees that we are left with the largest observed value, either the value calculated on the net capital stock in *t-1*, i.e., $K^1{}_t$, or the observed book value in *t-1* , i.e., BF_{t-}.

In step 2, we update the values on the capital stock to account for mergers or other factors such as when a firm's accountant revaluates a building or machinery (in this case, gross investments are substituted by - *I+S*). According to the Gelos and Isgut (2001) method, these updated values constitute the adjusted capital stocks.

Step 2: $K_{t-1} = \dfrac{K_t - I_t + S_t}{1-\delta}$ for $t \in [1, T]$.

Using this method means that we calculate a value on the capital stock for each year the firm is active in the database, except the last year. Thus, this version of the PI method allows us to adjust for specific events, such as mergers and revaluations of a firms capital. The method was originally used to adjust capital stocks where an initial book value may have been too low, i.e., under-estimated capital. Book values are actually not used in the PI method, but these can be informative as a quality control for the capital stock.