WORKING PAPER SERIES

WORKING PAPER NO 1, 2006

ESI

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http://www.oru.se/esi/wps

SE-701 82 Örebro
SWEDEN

ISSN 1403-0586

THE TWO FACES OF R&D: Does firm absorptive capacity matter?

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This paper examines the direct and indirect effect of firm R&D on total factor productivity growth. The R&D efforts do not only stimulate innovation but also enhance firms' ability to assimilate outside knowledge. We assume that the principal channel of transmission of new technology is through I/O relations. Econometric evidence suggests that in addition to a firm's own R&D expenditures, R&D spillovers embodied in traded goods within the industry, others imported from abroad, and technology spillovers transferred from the technological frontier within an industry are important determinants of firms' productivity growth. Results suggest that domestic R&D spillovers following the I/O links between industries are of minor importance in this respect. We also analyze whether firms' absorptive capacity matters for productivity growth. Analyzing absorptive capacity is particularly important for assessing the effective contribution of spillovers from other firms. The effect of a firm's absorptive capacity is found to interact positively with imported R&D spillovers, domestic rents spillovers seem to play a minor role for productivity growth.[*]

Keywords: TFP growth, R&D expenditures, R&D spillovers and absorptive capacity
JEL classification: O31; O33

[*] I am grateful to my supervisor Lars Lundberg and Patrik Gustavsson Tingvall, for their valuable help and comments during the process of this paper. Thanks go also to Joakim Gullstrand at Lund University who gave inspiring and insightful comments at the final seminar on this paper. Participants at the ETSG and Saltsjöbaden-conference are gratefully acknowledged. I would also like to express my sincere gratitude to *Jan Wallander and Tom Hedelius Forskningsstiftelse* for generous financial support.

1. Introduction

The accumulation of knowledge, in a broad sense, is the main factor behind productivity growth. Increases of knowledge may take different forms, such as new and better products, more efficient production techniques or improved methods of organising production, marketing or exporting. The improvements stem from many sources, some may be internal and some may be external to the firm. External knowledge may be dispersed among firms either through purchase or licensing, or as spillovers[1].

Griliches (1979) made a clear distinction between rent and knowledge spillovers. Rent spillovers are likely to be associated with trade in intermediate goods, when producers of knowledge and innovations are unable to charge the full quality price because of competition market pressure. This result in a productivity increase measured in the user industry. Knowledge spillovers, on the other hand, may follow many channels. Some of it may be transferred across firms following e.g. I/O channels, labour turnover or just being in the air. Bernstein and Nadiri (1988) classify knowledge spillovers as vertical or horizontal. Horizontal spillovers occur between competitors, and vertical spillovers flow between firms in different sectors.

We will focus on spillovers following I/O-links and within-industry catching-up. It is reasonable to assume that spillovers captured through I/O links are to a large extent rent spillovers. However, we are not able to trace spillovers generated by labour mobility and those related to the geographical distance between the source and user of new knowledge.

External knowledge spillovers may be created from R&D and spread via I/O flows to downstream firms. However, the actual amount of knowledge absorbed by receiving firms also depends on firms' own R&D. The R&D efforts therefore play a dual role and one may talk of "the two faces of R&D". That is, R&D activity does not only stimulate innovation but also enhances firms' ability to assimilate outside knowledge (see Cohen and Levinthal 1989). The second face of R&D is called the absorptive capacity and is considered to be very

[1] New innovations may in fact also be diffused and created among consumers. Although important, this aspect is not discussed in this paper because we only analyse and focus on the process of knowledge spillovers between firms.

important, particularly for assessing the effective contribution of spillovers from others. The absorptive capacity also includes the firm's ability to exploit outside knowledge of a more intermediate sort, such as basic research findings that provide the basis for subsequent applied research and development.

Absorptive capacity can be enhanced in a variety of ways. Studies have shown that firms' absorptive capacity may be created as a by-product of a firm's own R&D investments (see e.g. Tilton 1971, Allen 1977 and Movery 1983). Another suggestion is that absorptive capacity may be developed as a by-product of a firm's own manufacturing operations. Abernathy (1978) and Rosenberg (1982) have observed that direct involvement in manufacturing makes a firm more able to recognize and exploit new information. Production experience provides firms with information necessary to identify, evaluate and implement more efficient methods of production. In addition, firms invest and build up their absorptive capacity when their own employees are sent for training.

The vast majority of literature on the topic of absorptive capacity is focused on how firms' own R&D interacts with FDI and trade related spillovers. Most of these studies are found to disregard the significance of analyzing and measuring absorptive capacity effects via different forms of trade- or FDI spillovers. Since Sweden is an open economy, a central issue in this context is the impact of R&D spillovers from domestic- as well as international sources. Therefore, by analysing the influences of Swedish firms' absorptive capacity evaluated through these kinds of different sources of new knowledge, we may provide some new direction for policy reforms in the Swedish economy. Perhaps the government should promote firms by giving them subsidies to establish their R&D activities in Sweden in order to gain from domestic as well as international R&D spillovers.

The main objective of this paper is to analyse the influences of the firms' absorptive capacities via different forms of R&D spillovers on Swedish manufacturing firms' productivity growth. The second part of the objective concerns the relative role of the firms' absorptive capacities. More specifically; we are analysing whether the productive effects of absorptive capacities may differ through different sources of R&D spillovers (domestic as well as international).

The paper is organised as follows: The theoretical model and its extensions are presented in section two. In section three, we discuss the data. The fourth and fifth sections provide the results and conclusions.

1.1 Literature overview

Papers analyzing absorptive capacity indicate that the term *absorptive capacity* is not only used in economic literature but is also frequently cited in management and organization literature. The literature defines the absorptive capacity as the limit to the rate or quantity of scientific or technological information that a firm can absorb. If such limits exist, they provide one explanation for firms to develop internal R&D capacities. R&D departments can not only conduct development along lines they are already familiar with, but they have formal training and external professional connections that make it possible for them to evaluate and incorporate externally generated technical knowledge into the firm better than others in the firm (cf. Econterms).

The concept of the "two faces of R&D" was first established by Cohen & Levinthal (1989) in the classic article "*Innovation and Learning"*. They discussed and offered many theoretical implication of the dual role of R&D. Their research points to the fact that learning and thus technology adoption is affected by the character of the knowledge inputs. They further conjecture that an innovation which is purely capital embodied is less costly to adopt than more disembodied innovations that require more complementary internal effort and more pre-existing expertise in an area. Cohen and Levinthal assert that a product innovation developed on the basis of a well-established underlying knowledge base will diffuse more quickly among users than one grounded in a more recently developed body of scientific or technological knowledge.

Van Reenen *et.al* (2000) use a panel of industries across twelve OECD countries to investigate whether domestic R&D enhances absorptive capacity. They find that domestic R&D facilitates technology catch-up. Likewise, a study of the Norwegian business sector by Grűnfeld (2002) analyses the importance of absorptive capacity effects, claiming that positive contribution from R&D spillovers is an increasing function of the R&D activities carried out by economic agents. The paper found strong support for domestic as well as imported R&D

spillovers but no spillovers through foreign direct investments. The absorptive capacity effect enhances the productivity growth when R&D spillovers come through imports, but no such effects exist when spillovers occur through domestic intermediaries.

Karpaty and Lundberg (2004) investigated productivity effects, FDI spillovers and absorptive capacity for Swedish manufacturing firms 1990 – 2000. In addition to a positive contribution of FDI spillovers on productivity level, the paper found evidence for firm R&D enhancing the absorptive capacity of outside technology. The interactions of firms own R&D investments and industry- and region-specific FDI spillovers are positive and significant. Another contribution concerning the topics of productive FDI spillovers and related absorptive capacity was found in the Haskel, Pereira and Slaughter (2002) study of UK manufacturing firms 1973 – 1992. Instead of using a direct measure of absorptive capacity they split the sample of firms into three categories representing low, medium and high R&D percentiles by using information on three performance measures; skill intensity, TFP and employment. They found that the presence of foreign-owned firms enhances domestic plants' TFP. However, measures of foreign direct investments are found to be more important for plants at the lower end of the performance distribution.

Stock, Greis and Fischer (2001) investigated the potential for absorptive capacity to enhance the development of new and better modem products in the computer modem industry. Their results indicate that the relationship between absorptive capacity and new product performance is nonlinear. An "inverted-U shape relationship suggests diminishing returns for absorptive capacity.

There are few empirical papers that explore the contribution of absorptive capacity within transition economies. One exception is Kinoshita (2001). He uses a firm level panel data set on manufacturing sectors in the Czech Republic 1995 – 1998 and investigates the relative importance of two faces of R&D for firms' productivity assuming that knowledge flows occur through foreign direct investments. Kinoshita (2001) found the rate of return of investments in R&D to be about 14%. By including the absorptive capacity effects in his analysis, the direct effects of firms' own R&D becomes less important for productivity growth. It is found that those firms that engages in R&D activity benefit more from technology spillovers through FDI and also grows faster.

Mancusi (2004) analyzed six industrialised countries[2]; but measured the absorptive capacity in terms of self citations. She provides assessment of the effects of national and international knowledge spillovers on innovation at the sector level covering the period 1981 – 1995. The implied pattern of knowledge spillovers is through domestic- and international patent citation. International spillovers are found to increase the country's industry-specific innovative productivity. The empirical results show that absorptive capacity increases the elasticity of a country's innovation to both domestic and international spillovers. Deeds (2001) also used self-citation to measure absorptive capacity using a sample of 80 public pharmaceutical biotechnology firms' performance. The co-citation index was constructed using citations of scientific publications. Deeds (2001) found a strong and positive relationship between the wealth of pharmaceutical companies and their co-citations.

A slightly different approach is taken by Nieto and Quevedo (2005) to construct a measure of absorptive capacity. The measure is very much in line with the proposal of Cohen and Levinthal (1990), where qualitative factors[3] affecting the absorptive capacity within the organisation are captured. Controlling for industrial structural variables such as technological opportunity and knowledge spillovers, their measure of absorptive capacity proves to be positively correlated with the degree of innovation efforts among 406 Spanish firms.

In contrast to the relevant literature discussed above, the notion of absorptive capacity in this paper is found to be very similar to the one used in Van Reenen *et.al*, Cohen & Levinthal and Grűnfeld. The main departing point is in the modelling of the dual effects of firms' own R&D on productivity growth. We use a nonlinear absorptive capacity construction as proposed and postulated in Cohen & Levinthal. Simple linear absorptive capacity effects used and analysed in the Van Reenen *et.al* analysis are of minor importance in this paper and therefore left out for further investigation.

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[2] The surveyed units were Germany, France, Italy, Japan and the UK and the US.

[3] The qualitative factors were: 1) awareness of competitors' technologies, 2) awareness of competitors' needs, 3) staff skill, 5) investments in training, 6) capacity for technological development, 7) capacity to adapt technologies from other sources etc. Thereafter an index is constructed by aggregating the qualitative factors into an indicator which is defined as the sum of the effects of each of the factors on the innovatory success.

2. The empirical approach

Suppose the production function of firm i is expressed as:

$$Y_{ijt} = A_{ijt} F_j \left(S_{ijt}, U_{ijt}, K_{ijt}, M_{ijt} \right) \qquad (2.1)$$

where Y_{ijt} is total value of deflated sales, the inputs S_{ijt} and U_{ijt} are respectively skilled and unskilled labour, K_{ijt} is deflated book value of capital stocks, M_{ijt} corresponds to the deflated raw materials and energy, A_{ijt} is an index of total factor productivity (TFP).

Our index of TFP is a multilateral index developed by Caves *et al.* (1982) and extended by Good et al. (1997). The productivity index is calculated separately for each of the 22 two-digit industries in Swedish manufacturing. The multilateral index relies on a single reference point that is constructed as a hypothetical firm that has the arithmetic mean values of log output, log input and input cost share over all firms in the two-digit industry in each year. Each firm's logarithmic output and input levels are measured relative to this reference point in each year and then reference points are chain-linked over time. The total factor productivity index for firm i in industry j in year t is defined as:

$$ln(TFP_{ijt}) = (ln(Y_{it}) - \overline{ln(Y_{jt})}) + \sum_{s=2}^{t}(\overline{ln(Y_{js})} - \overline{ln(Y_{js-1})}) - [\sum_{j} 0.5(\mu_{ikt} + \overline{\mu}_{jkt})(ln(X_{ikt}) - \overline{ln(X_{jkt})})$$

$$+ \sum_{s=2}^{t}\sum_{j} 0.5(\overline{\mu}_{jks} + \overline{\mu}_{jks-1})(\overline{ln(X_{jks})} - \overline{ln(X_{jks-1})})] \qquad (2.2)$$

where lnY_{it}, lnX_{ikt} and μ_{ikt} represent the log output, log input of factor k and the cost share of factor k for firm i. $\overline{ln(Y_{js})}$, $\overline{ln(X_{jkt})}$ *and* $\overline{\mu}_{jkt}$ are the same variables for the hypothetical reference firm in the industry j in year t and are equal to the arithmetic mean of the corresponding variable over all firms in a specific industry and year. The index compares total factor productivity of each firm in each year to that of the hypothetical firm in the initial year. This productivity index is particular useful in analysing the cross sectional distribution of firms' productivity in levels for an industry and the movement of this distribution over time. Because the index measures only the relative productivity of firms in an industry, it cannot be used for productivity comparisons between industries.

Following the existing literature on R&D and TFP growth (see Griliches and Lichtenberg 1984), we assume that TFP is a function of the stock of R&D knowledge *(G_{ijt})* and an additional set of covariates *(B_{ijt})*, (see Van Reenen *et.al* 2000):

$$A_{ijt} = \psi(B_{ijt}, G_{ijt}) \tag{2.3}$$

Rearranging formula (2.3) by taking logarithms and differentiating with respect to time, gives the following:

$$\frac{\dot{A}_{ijt}}{A_{ijt}} = \nu_{ijt}\frac{\dot{B}_{ijt}}{B_{ijt}} + \eta_{ijt}\frac{\dot{G}_{ijt}}{G_{ijt}} \tag{2.4}$$

Where $\eta = (dA/dG)\cdot(G/A)$ is the elasticity of TFP with respect to the R&D knowledge stock *(G)* and $\nu = (dA/dB)\cdot(B/A)$ is the elasticity of TFP with respect to the residual set of influences *(B)*. The real R&D expenditures are denoted by R&D and the knowledge depreciation rate is ℓ. Assuming the depreciation rate ℓ is small, equation (2.4) may be rewritten in terms of the ratio of R&D expenditures to output:

$$\frac{\dot{A}_{ijt}}{A_{ijt}} = \nu\frac{\dot{B}_{ijt}}{B_{ijt}} + \rho\left(\frac{R\&D}{Y}\right)_{ijt} \tag{2.5}$$

Where the term $\dot{G} = R\&D - \ell G$ in (2.4) is substituted by *R&D/Y* and $\rho = dA/dG$ is the rate of return or marginal product of R&D. Then moving to discrete time we have (see Van Reenen et.al. 2000):

$$\Delta ln(A_{ijt}) = \nu\Delta ln(B_{ijt}) + \rho\left(\frac{R\&D}{Y}\right)_{ijt-s} \tag{2.6}$$

R&D activity is assumed to affect firms' productivity with time lags, it takes time to exploit the new innovation and then as a result use the new technology in the production more efficiently. Therefore, the R&D efforts are assumed to affect productivity with some lag.

The residual set of influences ΔlnB_{ijt} may be regarded as knowledge capital stocks created through the pool of spillovers. In evaluating the variable ΔlnB_{ijt}, we assume that the knowledge spillovers to firms in the *j*th industry from other industries at home or abroad can be measured as a weighted average of new knowledge produced in these sectors, measured by the R&D intensity in the sector, where the weights are given by domestic deliveries and imports of inputs from the different sectors.

The ΔlnB_{ijt} term may also be affected by technological transfers between firms in the same industry. For instance, non-frontier firms may gain from the technological leader in the industry. This implies that TFP growth in the frontier firms induces faster TFP growth in the follower firms by expanding their production possibility set. The speed of diffusion of technology will depend upon the levels of a firm's own TFP. A negative coefficient indicates a catching-up mechanism where followers are riding on the industry leading firm (Van Reenen *et.al.* 2000). Hence, ΔlnB_{ijt} can be approximated by the I/O weighted R&D spillovers and the measure of catching up:

$$\Delta ln(B_{ijt}) \approx f\left(ln(A_{ijt-1}), \sum_{l=1}^{L} b_{jl} \left(\frac{R\&D}{Y} \right)_{lt} \right) \tag{2.7}$$

The weights b_{jl} are computed from the Swedish input-output tables of 1995. This method can be described accordingly: The column vector of gross output, x_j, is decomposed according to the following formula:

$$x_j = \sum m_{jl}^D + \sum m_{jl}^F + \omega_j$$

where $m_{jl}^D, m_{jl}^F, \omega_j$ is cost of the *l*th good - domestic and imported, used in the *j*th sector, and value added (wage and capital cost etc) in the *j*th sector. A typical element in $\boldsymbol{M}$, m_{jl} reflects the amount of intermediate goods originating from sector l and being used by sector j. The technical coefficients are computed according to:

$$b_{jl} = m_{jl} / x_j$$

A typical element b_{jl}, shows the cost share of commodity l used in the unit production of j. The R&D spillover in (2.7) is assumed to be decomposed according to following formula:

"Within-industry spillovers":

$$r_{ijt}^{W} = b_{jj}^{D}\left(\frac{(R\&D_{jt} - R\&D_{ijt})}{(Y_{jt} - Y_{ijt})}\right)^{D} \qquad (2.8)$$

"Between-industry R&D spillovers":

$$r_{jt}^{B} = \sum_{l} b_{jl}^{D}\left(\frac{R\&D}{Y}\right)_{lt}^{D} \qquad (2.9)$$

"International R&D spillovers"[4]*:*

$$r_{jt}^{F} = \sum_{l} b_{jl}^{F}\left(\frac{R\&D}{Y}\right)_{lt}^{F} \qquad (2.10)$$

Substituting the spillover measure in (2.7) with components in (2.8) – (2.10) and rearranging (2.6) we have the basic model of productivity growth:

$$\Delta ln(A_{ijt}) = \alpha_1 ln(A_{ijt-1}) + \alpha_2 r_{ijt-s}^{O} + \alpha_3 r_{ijt-s}^{W} + \alpha_4 r_{jt-s}^{B} + \alpha_5 r_{jt-s}^{F} \qquad (2.11)$$

The measure of productive knowledge is a function of the firms' own R&D investments r^O and of the R&D spillovers, stemming from domestic industries, r^W (within industries) and r^B (between industries) and from abroad r^F.

Most studies within the productivity and absorptive capacity framework use an interaction between R&D intensity and the size of spillovers. However, this leaves no possibility for decreasing returns in spillovers. As extensively discussed in Cohen & Levinthal (1989), they

[4] A minor potential drawback of the measure of international R&D spillovers in 2.10 is that we do not have any possibility to weight the R&D expenditures with the import share of intermediates from each country in the OECD area.

postulate that a firm's capacity to absorb externally generated knowledge depends on its own R&D efforts and the characteristics of the underlying scientific and technological knowledge that affect the ease of learning from the environment. In their model, the absorptive capacity mechanism is assumed to increase with the firm's own R&D investments, though at a decreasing rate. In their equation of firm stock of knowledge, they do not solve for an explicit expression in modelling absorptive capacity. To the best of our knowledge we use an efficient approximation to the Cohen *et al.* measure of absorptive capacity used and motivated in Grűnfeld (2002) and Martin (2002):

$$\pi_{ijt} = \frac{ar^{O}_{ijt}}{1 + ar^{O}_{ijt}} \tag{2.12}$$

where π reflects the direct effects driven by variations in firms' r^{O} (R&D intensity) and a represents a learning parameter, that tells us how much the firms R&D helps learning from the R&D undertaken by competitor[5]. To keep our analysis tractable we set (a=1). The hyperbolic transformation (2.12) has the following desirable properties:

$$\lim_{r^{O} \to 0} \pi = 0 \qquad and \qquad \lim_{r^{O} \to \infty} \pi = 1$$

These properties allow for decreasing marginal returns in outside knowledge with respect to firms' own R&D investments. In what follows, we replace the firms' R&D intensity r^{O} by π in the expression for productive knowledge in (2.11), because the measure of direct- and indirect effects of firms' own R&D in specification (2.13) are then analytically consistent and comparable.

2.1 Other related productivity control variables

The true contribution from the return to scale economies may be unclear whenever using the multilateral productivity index in (2.2). Therefore we have included a scale parameter,

[5] The learning parameter *a* reflects the characteristics of outside knowledge that make R&D more or less critical to the maintenance and development of absorptive capacity which is treated as separate and additional component in the Cohen and Levinthal (1989) model of absorptive capacity.

measured as employment of the *i*th firm relative to the average employment at industry level to capture the economies of scale or firm size. This kind of measure may work as a control variable, which in a productivity framework seems to be an important determinant of firms' productivity growth, (see Girma and Görg (2003)) and (Karpaty and Lundberg (2003)).

Product market competition seems to be an important source to explain the variations in growth. Following the Schumpeterian approach, he argues that monopoly rent is what induces firms to innovate and thereby make the economy grow; product market competition can only be detrimental to growth. Recent works by Nickell (1996) and Blundell *et al.* (1995) point at a positive correlation between product market competition (as measured either by the number of competitors in the same industry or by the inverse of market share of profitability index) and productivity growth within the same industry. This conclusion is more consistent with the "Darwinian view" (see Porter (1990)), that market competition is good for growth because it forces firms to innovate in order to survive. As a measure of product market competition we apply the Herfindahl index *(H)* (see appendix for definitions).

Taken together, own R&D is expected to enhance productivity growth of the firm directly as well as indirectly through augmenting the absorptive capacity. Allowing for absorptive capacities to enter the model in 2.11, our econometric specification takes the following form (equation 2.13):

$$\begin{aligned}\Delta ln(TFP_{ijt}) = {} & \gamma_0 + \sum \gamma_{1i} D_i + \sum \gamma_{2t} D_t + \alpha_1 ln(TFP_{ijt-1}) + \alpha_2 \pi_{ijt-s} + \alpha_3 r^W_{ijt-s} + \alpha_4 r^B_{jt-s} + \alpha_5 r^F_{jt-s} \\ & + \alpha_6 [\pi][r^W]_{ijt-s} + \alpha_7 [\pi][r^B]_{ijt-s} + \alpha_8 [\pi][r^F]_{ijt-s} + \alpha_9 ln(H_{jt}) + \alpha_{10} ln(\sigma_{ijt}) + \varepsilon_{ijt}\end{aligned}$$

where j is the industry using spillovers, α are coefficients identifying the effective contribution of spillovers $(\alpha_3 - \alpha_5)$, the direct- (α_2) and indirect effects $(\alpha_6 - \alpha_8)$ and other control covariates.

3. Data

Data was collected from Statistics Sweden; Financial Statistics (*FS*). The dataset contains information on all manufacturing firms with at least 50 employees, spanning the period 1990 to 2000[6]. *FS* contains mainly information about the firms' input and output. The firm level statistics are based on annual census. All firms with at least 50 employees are requested to answer a questionnaire covering the required characteristics. Statistics Sweden has also, in cooperation with the tax authority, collected some information on firms not available in the census. About 50,000 firms are operating within the industrial parts of the financial statistics and among those, approximately 4 % are investigated by way of questionnaires. This figure corresponds to about 80 % of the value added in the industry[7]. Statistics Sweden; national account (*NA*) statistics also provide data on the I/O tables on the domestic deliveries- and imports of intermediate goods in the years 1989, 1995 and 2000.

Data on the R&D variable stem from the financial statistics and cover all firms with at least one employee active in R&D activities at a minimum of 50% of full time. The financial statistics are collected annually and it is compulsory for firms to reply. Respondents are asked to give an exact figure for R&D expenditures or to answer in an interval scale. The R&D expenditures of the OECD area are collected from the OECD ANBERD database. Those figures are converted by a GDP deflator and a PPP index for each of the countries in the OECD.

[6] R&D expenditures and intermediate goods consumption (including energy and raw material) are only available for firms in the manufacturing sector with at least 50 employees. Our Swedish industry level data are consistent with ISIC classification code (sni92) only for the period of 1990 - 2000.

[7] http://www.scb.se

4. Econometric analysis

The econometric specification derived in equation (2.13) is initially estimated as a simple productivity growth model without spillovers. Thereafter, we extend our analysis of TFP growth in a stepwise manner by adding measures of R&D spillovers and absorptive capacities to the firms' own R&D. Since we are dealing with a dynamic productivity specification, we apply an Arrelano & Bond estimation technique (GMM) which is solved for a consistent estimate in α_S by taking the first difference to eliminate the individual firm-specific effects γ_{1i}.

Table 3: Dependent variable; growth of total factor productivity

Independent variable	GMM (mod 1)	GMM (mod 2)	GMM (mod 3)	GMM (mod 4)	GMM (mod 5)	GMM (mod 6)
ln(TFP)	-0.42 (t-1)	-0.45 (t-1)	-0.44 (t-1)	-0.45 (t-1)	-0.45 (t-1)	-0.45 (t-1)
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
π	0.033 (t-1)	0.047 (t-1)	0.049 (t-1)	0.047 (t-1)	0.048 (t-1)	0.046 (t-1)
	(0.015)**	(0.027)**	(0.024)**	(0.025)**	(0.024)**	(0.027)**
r^W	-	0.081 (t-3)	0.073 (t-3)	0.081 (t-3)	0.062 (t-3)	0.061 (t-3)
	-	(0.020)**	(0.036)**	(0.019)**	(0.079)*	(0.020)**
r^B	-	0.234 (t-3)	0.234 (t-3)	0.232 (t-3)	0.195 (t-3)	0.203 (t-3)
	-	(0.106)	(0.105)	(0.112)	(0.180)	(0.166)
r^F	-	0.066 (t-4)	0.067 (t-4)	0.067 (t-4)	0.076 (t-3)	0.072 (t-3)
	-	(0.056)*	(0.058)*	(0.056)*	(0.030)**	(0.037)**
$[\pi][r^W]$	-	-	0.014 (t-4)	-	-	-0.030 (t-4)
	-	-	(0.715)	-	-	(0.608)
$[\pi][r^B]$	-	-	-	0.005 (t-4)	-	-0.133 (t-4)
	-	-	-	(0.935)	-	(0.222)
$[\pi][r^F]$	-	-	-	-	0.039 (t-4)	0.075 (t-4)
	-	-	-	-	(0.026)**	(0.057)*
ln(H)	- 0.003 (t)	0.009 (t)	0.010 (t)	0.009 (t)	0.009 (t)	0.009 (t)
	(0.742)	(0.490)	(0.488)	(0.488)	(0.511)	(0.505)
ln(σ)	-0.101 (t)	-0.098 (t)	-0.100 (t)	-0.098 (t)	-0.098 (t)	-0.100 (t)
	(0.001)**	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Firm effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Sargan test	122.5***	112.1**	117.2***	112***	109***	114**
AR(2) test	2.35**	2.37**	2.37**	2.37**	2.35**	2.37**
Observations	12902	6730	6726	6726	6726	6726

Note: p-values within brackets. ***,**,* indicate significance at 1, 5 and 10% levels respectively.

In table 3 above, we present the econometric results. At first, as a determinant of the rate of innovation and productivity growth, the direct effects of firms' own R&D investments are found to be significant at 5% level and the size of the parameter estimate seems to be stable irrespective of the choice of econometric specification. Although we use a hyperbolic transformation in firms' R&D expenditures, our results seem to be very similar to other studies using the firms' R&D intensity as a direct measure (see Mairesse 1991) of innovation.

In a productivity growth context, not only firms' own R&D, but also outside knowledge is important. In fact, for a single firm, outside knowledge may be more important than their own R&D. Outside knowledge may consist of rent- or knowledge spillovers originated within or between industries or imported from abroad. We will therefore analyse all of these channels for spillovers in more detail.

Our regression analysis of rent spillovers reveals an interesting pattern. Innovations introduced in one industry and following I/O linkage are expected to boost productivity growth in other industries abroad, and within the own country. By using the firm level data, we are able to identify that R&D spillovers have a clear and precise effect on productivity growth. Results suggest that the within-industry R&D spillovers seem to explain the productivity growth, not the corresponding between-industry R&D spillovers. There is no support of productive R&D spillovers following the I/O linkage between industries in Swedish manufacturing.

Rent spillovers do not only stem from domestic sources. International trade and the increasing globalization may also affect the flow of external knowledge. From the econometric analysis, we can observe such R&D spillovers stemming from abroad. The results point at a positive and significant contribution from the R&D spillovers from other countries. These results are well in line with similar studies where R&D spillovers are found to enhance the productivity growth at firm level. In comparison with similar studies, the positive returns on R&D spillovers received from international sources were also found in previous Norwegian studies based on a similar productivity growth specification (see Grűnfeld 2002). This conclusion is also supported in a study (Hanel 2000) of Canadian industry data.

There may be more factors than I/O flows that determine the total volume of knowledge flows, there are probably other spillovers such as technology spillovers which dominate in a particular industry. If technology diffuses between firms via other channels than I/O links, this means that firms in the same industry may gain from the leading frontier firm in that industry.

Such processes will give rise to productivity convergence between firms. In contrast to Van Reenen *et al.* (2000), we use the lag of firms' TFP in levels as a measure of catching up. Our econometric evidence in table 3 indicates that the parameter of lagged TFP is negative and significant, indicating a robust evidence of productivity convergence among firms within a specific industry.

Next, we extend our analysis by including the measure of firms' absorptive capacity and analyze its relative influence on Swedish firms' productivity growth. The overall impression from our regressions above is that there are mixed results with respect to firms' absorptive capacity effects. The effects are positive but only significant in the fifth model, indicating that the absorptive capacity via imported R&D spillovers has some persistent impact on firms' productivity growth. In that sense, it appears that there are complementarities between these firms conducting active R&D efforts and R&D spillovers following the I/O flows from abroad. Those firms may themselves have a comparative advantage in terms of assimilating and learning new outside knowledge stemming from abroad. Otherwise, the flow of domestic R&D spillovers, the within industry- and between-industry R&D spillovers do not contribute to firms' absorptive capacities.

In evaluating the relative influences of absorptive capacity effects in model 6, we test the equality of regression coefficients α_6 – α_8. The F-test does not reveal any systematic difference between the various absorptive capacity measures. This may to some extent be explained by the strong correlation between different measures of absorptive capacity (see table A2). As a final note, assuming that the effects of absorptive capacity enter in the productivity growth equation as a multiplicative and linear form as in Griffith, Redding and Van Reenen (2000) this does not reveal any support of absorptive capacities among Swedish manufacturing firms.

Having checked for firm size effect, the picture from all models points in favour of a negative relationship between the relative firm size and productivity growth, i.e. small firms tend on average to have a comparative advantage over large firms in a productivity growth context. It seems reasonable to assume that small firms are more efficient than larger ones perhaps because of the rigidity of the organisational structure, monitoring inefficiency by supervision in the larger firms and inability to adapt production flows to the rapid changes in our economic environment and more. Finally, in our analysis of competition and productivity growth, we apply the time and industry specific Herfindahl index as our measure of product market competition. The Herfindahl index uses a scale from 0 – 10,000 where a value of 10,000 indicates a situation of monopoly. The output from the regressions analysis above reveals an insignificant effect with respect to market concentration on productivity growth.

We now proceed to disentangle the impact of absorptive capacities between high and low productive firms. The idea is to use a percentile regression approach on specification (2.13), where we seek to compare and discriminate the effects of absorptive capacity and productive spillovers between firms representing the 10th and 90th percentiles respectively. Using such an approach, we are able to test the hypothesis that productive firms on average are more efficient in absorbing and assimilating outside new knowledge.

Table 4: Percentile regressions – growth of TFP

Independent variable	(mod 7)		(mod 8)		(mod 9)	
	Q10	Q90	Q10	Q90	Q10	Q90
π	-0.007 (t-1)	0.011 (t-1)	-0.003 (t-1)	0.011 (t-1)	-0.004 (t-1)	0.010 (t-1)
	(0.476)	(0.363)	(0.804)	(0.360)	(0.726)	(0.415)
r^W	0.003 (t-3)	0.031 (t-3)	0.004 (t-3)	0.039 (t-3)	0.006 (t-3)	0.043 (t-3)
	(0.878)	(0.177)	(0.837)	(0.086)*	(0.787)	(0.014)**
r^B	0.078 (t-3)	0.037 (t-3)	0.074 (t-3)	0.002 (t-3)	0.072 (t-3)	0.025 (t-3)
	(0.011)**	(0.266)	(0.054)*!!	(0.962)!!	(0.024)**	(0.473)
r^F	-0.027 (t-3)	-0.006 (t-3)	-0.023 (t-4)	-0.001 (t-4)	-0.025 (t-3)	-0.12 (t-3)
	(0.000)***	(0.608)	(0.038)**!!	(0.898)!!	(0.079)*	(0.355)
$[\pi][r^W]$	0.005 (t-4)	0.066 (t-4)	-	-	-	-
	(0.842)	(0.031)**	-	-	-	-
$[\pi][r^B]$	-	-	-0.035 (t-4)	0.059 (t-4)	-	-
	-	-	(0.452)!	(0.180)!	-	-
$[\pi][r^F]$	-	-	-	-	-0.007 (t-4)	0.025 (t-4)
	-	-	-	-	(0.579)!!	(0.002)**!!
ln(H)	0.016 (t)	0.009 (t)	0.016 (t)	0.010 (t)	0.016 (t)	0.010 (t)
	(0.001)**	(0.020)**	(0.000)***	(0.028)**	(0.000)***	(0.057)*
ln(σ)	0.002 (t)	0.001 (t)	0.004 (t)	0.003 (t)	0.003 (t)	0.001 (t)
	(0.466)	(0.789)	(0.159)	(0.431)	(0.543)	(0.653)
Year effects	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
R^2 adjusted	0.04	0.24	0.04	0.25	0.04	0.24
Bootstrappings	20	20	20	20	20	20
Observations	8510	8510	8510	8510	8510	8510

Note: p-values within brackets. *** ** * indicate significance at 1, 5 and 10% levels respectively. !!! !! ! indicate coefficients in 10th respective 90th percentile are statistically significantly different at 1, 5 and 10% levels. The statistical programme routine in the software *Stata* chooses the default value of number of bootstraps equal to 20 iterations.

Firstly, there are a few interesting questions that appear when studying the regressions in table 4. Analysing the direct effect of the firm's own R&D activities, the picture is not very distinct, we are not able by means of a percentile regression framework to discriminate between firms positioned near the two percentiles by F-test. In all models, the direct effects are found to be insignificant and hence they are difficult to interpret.

Interpreting the process of rent spillovers, a fairly clear pattern appears. Our econometric results in model 8 indicate that low-productive firms gain marginally more than the productive firms in receiving domestic between-industry R&D spillovers. This conclusion is rather reversed whenever we confine our attention to the impact of international R&D spillovers, although the effects themselves are only significant in the 10^{th} percentile, the difference between firms is only significant in model 8. It seems that R&D spillovers from abroad have an unexpected contradictory impact on firms' productivity growth. Finally, our regression results with respect to the within-industry R&D spillovers do not provide us with any clear evidence.

The absorptive capacities give rise to some interesting implications for policy evaluations, considering models 8 and 9, our evidence points at the existence of some incremental absorptive capacity effect accruing to high-productive firms through between-industry and international R&D spillovers. These coefficients are significant and they appear to be statistically different among high- and low-productive firms. Otherwise, we do not find any statistical evidence of increasing productivity gains toward high-productive firms through within-industry R&D spillovers. Furthermore, we cannot detect any tendency when we focus on our control covariates; neither Herfindahl nor the firms' relative size reveals any clear and systematic pattern among the firms.

Robustness of results

Essays by Cohen & Levinthal (1989) and Gustavsson & Poldahl (2003) have shown that R&D expenditures at firm level are found to be endogenous. Shocks to the economic environment can certainly feedback into firms' R&D. Rather, we assume that the current level of R&D expenditure cannot predict the future economic shocks; hence IV models are therefore not given in the econometric section. The econometric specifications have also been checked for lag lengths and outliers, the goodness of fit measure (R^2) supports using long time lags for R&D spillovers and a maximum of 1 lag for π. Otherwise, the regressions are found to be very robust with respect to the inclusion of influential outliers of our explanatory variables or not.

5. Concluding remarks

Our econometric evidence in this essay suggests that the relationship between firms' R&D activities and the growth of TFP is strong. R&D efforts seem not only to cause productivity growth directly, but also indirectly through innovations by competitors and other firms.

Analyzing the impacts of productive R&D spillovers, our empirical results indicate that domestic as well as international R&D spillovers have a positive and strong influence on the Swedish firms' TFP growth. The exception is that the between-industry R&D spillovers fail to stimulate the firms' productivity performance. Furthermore, the results also confirm that the significance of technological diffusion not related to the I/O linkage is to some extent captured in the catching up among firms.

The second role of firms' R&D investments seems to be mixed, depending on whether we assume the source of R&D spillovers to be domestic or international. The evidence suggests that the pattern of absorptive capacity among firms only matters when R&D innovations are embedded in the imports from abroad. There is also evidence in favour of increasing absorptive capacities of productive firms in Swedish manufacturing. These firms may have more highly skilled employees in their production. This in turn may help those firms in assimilating and absorbing new external knowledge via the domestic inter-sectoral linkage and international sources of R&D spillovers.

There are some additional questions raised during the writing process of this paper. For future work, it would be interesting to extend our econometric specification to allow for countries within the OECD area and make inter-country comparisons with respect to productive R&D spillovers and absorptive capacity effects.

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Appendix

Variable definitions

Below we present additional descriptions of selected variables. Our choice of subscript is defined as follows; i = firms, t = time index, j = industry according to 2-digit SNI 92.

1. TFP: Total factor productivity. (measured by means of Multilateral productivity index[8]). Source: Statistics Sweden/Financial Statistics.

2. R&D: Total Research and Development expenditures[9] in 1990 constant prices. Source: Statistics Sweden/Research Statistics.

3. Y: Total value of Sales in 1990 constant prices. Source: Statistics Sweden/Research Statistics.

4. Domestic within-industry R&D spillovers. Derived from the international I/O tables, computed at 2-digit level. Source: SCB/Financial Statistics, SCB.

$$r_{ijt}^{W} = b_{jj}^{D}\left(\frac{(R\&D_{jt} - R\&D_{ijt})}{(Y_{jt} - Y_{ijt})}\right)^{D}$$

5. Domestic inter-industry R&D spillovers. Derived from the international I/O tables, computed at 2-digit level. Source: SCB/Financial Statistics, SCB.

$$r_{jt}^{B} = \sum_{l} b_{jl}^{D}\left(\frac{R\&D}{Y}\right)_{lt}^{D}$$

[8] See also Sukkyun & Roberts, 2003 for a more technical discussion of the index.

[9] R&D is an activity that 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).

6. 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.

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

7. R&D activity. Source: SCB/Financial Statistics, SCB.

$$\pi = \frac{ar_{it}^{O}}{1 + ar_{it}^{O}}$$

8. Market concentration:

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

9. The measure of scale parameter (see Karpaty & Lundberg, 2003) is constructed using the following formula:

$$Relative\ firm\ size,\ \sigma_{ijt} = \frac{employees_{ijt}}{N^{-1} \sum_{i=1}^{N} employees_{ijt}}$$

Summary statistics and index definitions

Table A1: Deflators:

Deflators	Description	Source	Variable
PPI	Aggregated producer price index	SCB homepage	R&D
PRODINDEX	Disaggregated producer price index	SCB homepage	Output, exports 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 goods producer price index	SCB homepage	Imports
KPI	Aggregated consumer price index	SCB homepage	Wages

Table A2: Correlation matrix

	ln(TFP)	π	r^W	r^B	r^F	$[\pi][r^W]$	$[\pi][r^B]$	$[\pi][r^F]$	ln(H)	ln(σ)
ln(TFP)	1.0000									
π	0.0438	1.0000								
r^W	0.0905	0.2184	1.0000							
r^B	0.0592	0.1010	-0.0733	1.0000						
r^F	0.1459	0.2990	0.5641	0.4234	1.0000					
$[\pi][r^W]$	0.0720	0.6966	0.5786	-0.0386	0.3987	1.0000				
$[\pi][r^B]$	0.0484	0.8775	0.1120	0.3759	0.3462	0.5054	1.0000			
$[\pi][r^F]$	0.0984	0.7946	0.3297	0.1813	0.5804	0.7467	0.7715	1.0000		
ln(H)	0.0554	0.1467	0.6053	-0.0525	0.5639	0.3276	0.0817	0.3082	1.0000	
ln(σ)	0.0225	0.2475	-0.2356	0.0444	-0.1404	0.0798	0.2277	0.1512	-0.2124	1.0000

Table A3: Variance decomposition

Variable	Overall standard deviation	Within standard deviation	Between standard deviation
ln(TFP)	0.50	0.33	0.44
π	0.32	0.15	0.27
r^W	0.25	0.11	0.24
r^B	0.13	0.04	0.12
r^F	0.67	0.08	0.68
$[\pi][r^W]$	0.15	0.07	0.12
$[\pi][r^B]$	0.10	0.05	0.09
$[\pi][r^F]$	0.39	0.16	0.34
ln(H)	0.95	0.63	0.76
ln(σ)	0.95	0.26	0.89

Table A4: Industry code

SN92	Industry	SNI92	Industry
15	Food	26	Non-mineral products
16	Tobacco	27	Basic metals
17	Textiles	28	Metal products
18	Clothing	29	Machinery and equipment
19	Leather	30	Computer
20	Wood and furniture	31	Electrical machinery
21	Pulp and paper	32	Communication
22	Publishers and printers	33	Medical, precision and optical instruments
23	Refineries	34	Motor vehicles
24	Chemicals	35	Other transport equipment
25	Rubber and plastic	36	Other manufacturing

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