

THE TWO FACES OF R&D: Do firm's absorptive capacities matter?

By

ANDREAS POLDAHL

Örebro University

Department of Economics, Statistics and Informatics (ESI), Sweden

This paper examines the direct and indirect effect of firms own R&D on total factor productivity among Swedish manufacturing firms. The R&D efforts do not only stimulate innovation but also enhance firms' ability to assimilate outside knowledge. The paper assumes 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, spillovers stemming from the imports of intermediates from abroad and follow the technology gap are important determinants of firms' productivity. The domestic R&D spillovers following the I/O links between industries seem to be of minor importance in this respect. Realising that a firm's productivity is not only caused by its own R&D and knowledge spillovers, the firm's absorptive capacity also contributes. This is very important particularly for assessing the effective contribution of spillovers from other firms. The effect of a firm's R&D is found to interact positively with knowledge spillovers generated within the own industry, as well as domestic and imported rents spillovers.*

Keywords: TFP, R&D expenditures, R&D spillovers and Absorptive capacity

JEL classification: O31; O33

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1. Introduction

The accumulation of knowledge, in a broad sense, is the main factor behind productivity. 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 of them may be internal or external to the firm. External knowledge may be dispersed among firms either through purchase, licensing or as spillovers.

Since Griliches' (1979) article, there is a clear distinction between rent and knowledge spillovers. Rent spillovers are likely to be associated via trade in intermediate goods, the case when a quality improvement of the intermediate is not fully reflected in its price results in a productivity increase measured in the user cost. Knowledge spillovers may follow other channels than I/O links, such as the copying of new products and production methods from competitors or by labour turnover. These may be called horizontal spillovers even though some knowledge spillovers may be vertical and follow I/O channels.

Though we may capture most rent spillovers, other forms of spillover, especially those among firms in the same industry may follow other channels than I/O flows. In this framework, we are not able to trace such horizontal spillovers which do not follow the I/O links, such as those generated by labour mobility and inward FDI investments. These diffusion mechanisms are very important, this paper is focused on vertical spillovers following I/O flows. However we may also capture some horizontal spillovers to the extent that they are reflected in a catching-up of firms with a low initial level of productivity, driven by knowledge spillovers from the highly productive firms.

The potential of external knowledge may be created from R&D in producer sector and spread via I/O flows to the user, but the actual external knowledge also depends on firms' own R&D. The R&D efforts by the firm plays a dual role called "the two faces of R&D". That is, R&D activity does not only stimulate innovation but also enhance 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 important particularly for assessing the effective contribution by 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 showed that firms' absorptive capacity may be created as a byproduct of a firms own R&D investments (see e.g. Tilton 1971, Allen 1977 and Moverly 1983). Other suggestion is that absorptive capacity may be developed as a byproduct of a firm's own manufacturing operations. Abernathy (1978) and Rosenberg (1982) have observed that direct involvement in manufacturing, a firm is better able to recognize and exploit new information important for a specific product market. Production experience provides firms with information necessary to identify, value and implement more efficient methods of production. In addition, firms invest and build up their absorptive capacity, when their own employees are sent for advanced technical training.

The vast majority of literature within the topics of absorptive capacity is found to be focused toward the impact of absorptive capacity matched with foreign direct investment flows and trade related spillovers (see literature survey). The empirical studies are found to be scarce in evaluating and modelling the impact of the firms/industry own R&D in association with many sources of spillovers. Therefore by this essay we provide an extensive analysis of the role of "the two faces of R&D" in context of various forms of spillovers. Aside the well investigated topics of own R&D and productive spillovers (see Poldahl 2004 for an extensive literature survey), we seek to identify and measuring the importance of the firms' absorptive capacity for different kinds of spillovers originated within the own industry and following the rent spillovers embedded in the transactions between domestic industries and imports from abroad. The study uses data for all firms' in the Swedish manufacturing in the period 1990 – 2000 with at least 50 employees.

The paper is organised as follows: The theoretical model and its extensions are presented in section 2. In section 3, 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* not only has been used within the economic literature but also frequently cited in the management- and organization literature. The firms' absorptive capacity can be measure in a lot of ways, in what is review below we presenting the most cited articles within this topics and how they embarked on their measurement of absorptive capacity.

The concept of the “two faces of R&D” was first established by Cohen & Levinthal (1989) writings of the classical article “*Innovation and Learning*”. They discussed and offered many theoretical implication of the dual role of R&D. Their research points at 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 asserts that 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, enhance absorptive capacity. They find that domestic R&D facilitates technology catch-up. Likewise, a study of the Norwegian business sector by Grúnfeld (2002) analyze 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. He 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.

A study of Karpaty & Lundberg (2004) investigates the productivity, FDI spillovers and absorptive capacity for Swedish manufacturing firms 1990 – 2000. They found aside from the positive contribution of FDI spillovers on productivity level, evidence that points at existence of absorptive capacity by domestic firms. The interactions of own firms R&D investments

and industry- and region specific FDI spillovers are positive and significant. Another contribution within the topics of productive FDI spillovers and related absorptive capacity were found in Haskel, Pereira and Slaughter (2002) study of UK manufacturing firms 1973 – 1992. Instead of using a direct measure of absorptive capacity they splitting up the whole sample into three categories representing low, medium and high R&D percentiles by using information on three performance measure; skill intensity, TFP and employment. They arrived to the findings of presence of foreign ownership measured at industry level enhance the UK domestic plants TFP, but those measures of foreign direct investments at industry and region level are found to be more important for plants at the lower end of the performance distribution.

Absorptive capacity has also showed to be important for new products development, there new products developed by firms tend to benefit from the acquisitions and use of external information. Stock, Greis and Fischer (2001) investigates the potential for absorptive capacity for new better and efficient modem products in the computer modem industry in year 1976 – 1993. The absorptive capacity is operationalised by R&D intensity. Their results indicate that the relationship between absorptive capacity and new products is nonlinear, which in some sense give support of the idea of diminishing returns for learning.

There are few empirical papers that explore the contribution of absorptive capacity within transition economies. A study performed by Kinoshita (2001) for a firm level panel data set on manufacturing sectors in Czech 1995 – 1998. Kinoshita investigates the relative importance of two faces of R&D for the firms' productivity by assuming the knowledge flows occur through foreign direct investments. The rate of return of investments in R&D is shown 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', which engage in R&D activity, benefit more from technology spillovers through FDI and grow faster.

Aside from the traditional way of measuring absorptive capacity by means of own firms/industries R&D activities, there exist an survey performed by Mancusi (2004) on six industrialised countries¹; measuring absorptive capacity in terms of self citations. She

¹ The surveyed units were Germany, France, Italy, Japan and UK and US.

provides assessment of the effects of national and international knowledge spillovers on innovation at sector level over the period of period 1981 – 1995. The implied pattern of knowledge spillovers are through domestic- and international patent citation, there 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. Using self citation analysis for measuring absorptive capacity was also found in Deeds (2001) analysis of 80 public pharmaceutical biotechnology firms' performance. A co-citation index was constructed using citations of scientific publications. The author did find strong and positive relationship between 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 causing the absorptive capacity within the organisation are captured. Controlling for industrial structural variables as technological opportunity and knowledge spillovers, their measure of absorptive capacity shows to be positive correlated with the degree of innovation efforts among 406 Spanish firms.

2. The theoretical approach

Suppose the production function of firm i is expressed as:

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

where Y_{ijt} is total value of sales, S_{ijt} and U_{ijt} are respectively skilled and unskilled labour, K_{ijt} is physical capital, M_{ijt} corresponds to the inputs of intermediate goods, A_{ijt} is an index of technical efficiency or total factor productivity (TFP). This variable may be constructed by means of the Törnqvist² index (see Gunnarsson and Mellander, 1999; Harper, Berndt and Woods, 1989). The Törnqvist TFP index is simply the difference between the logarithm of Y and the input quantity index X :

$$\ln TFP_{it} = \ln Y_{it} - \ln X_{it} \quad (2.2)$$

Where:

$$\ln X_{it} = \sum_{k=1}^K \bar{w}_{jkt} \ln X_{ikt}$$

The \bar{w}_{jkt} are weights defined in terms of average cost shares for the k th factor in the j th industry according to

$$\bar{w}_{jkt} = \frac{1}{2} \left(\frac{P_{j,k,t-1} X_{j,k,t-1}}{\sum_{k=1}^K P_{j,k,t-1} X_{j,k,t-1}} + \frac{P_{j,k,t} X_{j,k,t}}{\sum_{k=1}^K P_{j,k,t} X_{j,k,t}} \right)$$

where P_k is price of input $k=1, \dots, K$, $t=1, \dots, T$ indexes time, $i = 1, \dots, N$ denotes firms and $j = 1, \dots, J$ denotes industries. In equation (2.1) above, Y_{it} is deflated sales, $X_{it} = (U_{it}, S_{it}, M_{it}, K_{it})$

² The Törnqvist index is based on a Translog production function with assumption of no constant return (see Coelli, Rao and Battese 1998).

is the employment of unskilled – and skilled workers, inputs of deflated raw materials and energy and, deflated book value of capital stocks of the it h firm.

A_{ijt} is assumed to be related to knowledge capital stocks of the firm as follows (see Van Reenen 2002):

$$A_{ijt} = F(B_{ijt}, G_{ijt}) \quad (2.3)$$

where G_{ijt} is the internally created by its own R&D part of its knowledge capital stock and B_{ijt} is the external part created by various forms of knowledge spillovers. The R&D capital stocks are accumulated over time by investments in knowledge and technology. The internal knowledge capital stocks G_{ijt} are approximated by firms' R&D intensity measured by R&D expenditures over total value of sales. Construction of R&D capital stocks are by cumulating R&D expenditures over time is not possible due to the short time period. Whether using R&D or R&D intensity as proxies is dependent on the assumption on the number of products produced by the firm. Assuming a case of multi-product firm where firm size and number of different products are correlated and no economies of scope in R&D, the R&D intensity is the most appropriate measure.

The residual set of influences B_{ijt} may be regarded as knowledge capital stocks created through the pool of spillovers. In evaluating the variable B_{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 knowledge capital stocks may also be generated by the technological transfer between firms in the same industry. For instance, non-frontier firms may gain from the technological leader in the industry. This implies that TFP 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 relative levels of a firm's own TFP, since TFP in a non-frontier firms lies behind the leader, the coefficient of TFP is positive (Reenen et.al. 2000).

Hence, B_{ijt} can be approximated by the I/O weighted R&D spillovers and the measure of technological gap:

$$B_{ijt} \approx g \left(Tgap_{ijt}, \sum_{l=1}^L b_{jl} \left(\frac{R \& D}{Y} \right)_{lt} \right) \quad (2.4)$$

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 formulae:

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

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 \mathbf{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 (2.4) is assumed to be decomposed according to following formulae:

“*Between-industry R&D spillovers*”:

$$r_{jt}^B = \sum_l b_{jl}^D \left(\frac{R \& D}{Y} \right)_{lt}^D \quad (2.5)$$

”*International R&D spillovers*”:

$$r_{jt}^F = \sum_l b_{jl}^F \left(\frac{R \& D}{Y} \right)_{lt}^F \quad (2.6)$$

Substituting the spillover measure in (2.4) with components in (2.5) and (2.6) and rearranging (2.4) we have the basic model of productivity:

$$A_{ijt} = \rho(r_{ijt-s}^O, Tgap_{ijt-s}, r_{jt-s}^B, r_{jt-s}^F) \quad (2.7)$$

The measure of productive knowledge is therefore a function of the firms' own R&D efforts ($r^O = R\&D/Y$), technology transfers generated within the industry $Tgap$ and R&D technology spillovers stemming from domestic industries, r^B (between industries), from abroad r^F (through imports).

Most studies within the productivity and absorptive capacity framework using a simple interaction between R&D intensity and the size of spillovers, but henceforth there is no possibility for decreasing returns in spillovers. A possibly more realistic but also more complex learning function is the one that is based on the logistic learning curve, where the marginal gain from investing in learning capacity is large for low investments levels (see Karshenas and Stoneman 1995). Since the logistic function is more complex, the absorptive capacity becomes hard to calculate. Thus, we choose a simple concave function found and motivated in Grúnfeld (2002):

$$Acap_{ijt} = \frac{r_{ijt}^O}{1 + r_{ijt}^O} \quad (2.8)$$

Where, $Acap$ reflect the absorptive capacity and is driven by variations in firms' r_{ijt}^O (the firm's own R&D intensity). This concave function has the following desirable properties:

$$\lim_{r_{ijt}^O \rightarrow \infty} Acap = 1 \quad \text{and} \quad \lim_{r_{ijt}^O \rightarrow 0} Acap = 0$$

A fulfilment of these limit properties allows for decreasing marginal returns in absorptive capacity with respect to firms own R&D investments.

Taken together, increasing the own R&D are expected to enhance the productivity directly through the own innovation and indirectly through augmenting the absorptive capacity. By adding for interactions of absorptive capacity in (2.8) our econometric specification takes the

following form (here we assume that each variable enters in an additive form explaining TFP in levels):

$$\begin{aligned} \log A_{ijt} = & \alpha_0 + \alpha_i + \alpha_t + \alpha_1 r_{ijt-s}^O + \alpha_2 \log(Tgap_{ijt-s}) + \alpha_3 \log(r_{jt-s}^B) + \alpha_4 \log(r_{jt-s}^F) + \\ & \alpha_5 Acap_{ijt} \cdot \log(Tgap_{ijt-s}) + \alpha_6 Acap_{ijt} \cdot \log(r_{jt-s}^B) + \alpha_7 Acap_{ijt} \cdot \log(r_{jt-s}^F) + \varepsilon_{ijt} \end{aligned} \quad (2.9)$$

where j is the industry using spillovers, α are empirically determined parameters identifying the effective contribution of spillovers and the direct- and indirect effect of own firms R&D activities.

3. Data

Data are collected from Statistics Sweden; Financial Statistics (*FS*) and Regional Labour Statistics (*RAMS*). These datasets contain information on all manufacturing firms with at least 50 employees, spanning the period 1990 to 2000³. *RAMS* contain mainly information on employees' education and wages while *FS* contain 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 50000 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 industry⁴.

Inspecting the appending chart below, some interesting findings appears. Dividing the sample according to the percentiles of R&D distribution to depict increasing absorptive capacity, table 1 give support of R&D intensive firms have higher potential for I/O driven spillovers but

³ 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.

⁴ <http://www.scb.se>

not of course for catching up, likewise the firms' absorptive capacities also appear to expand which is to be expected.

Table 1; 95 % confidence intervals year 1995 (conditional on R&D intensity)

Variables	25 th		25 th – 75 th		75 th	
log(TFP)	{1.99	2.13}	{2.12	2.19}	{2.15	2.28}
Tgap	{48.7	55.2}	{44.1	47.8}	{40.7	47.0}
r ^B	{2.1e ⁻³	2.2e ⁻³ }	{2.4e ⁻³	2.5e ⁻³ }	{2.5e ⁻³	2.6e ⁻³ }
r ^F	{4.7e ⁻³	4.9e ⁻³ }	{7.2e ⁻³	7.4e ⁻³ }	{1.1e ⁻²	1.2e ⁻² }
[Acap][Tgap]	{5.41	6.49}	{22.3	24.5}	{34.8	40.3}
[Acap][r ^B]	{2.2e ⁻⁴	2.8e ⁻⁴ }	{1.2e ⁻³	1.3e ⁻³ }	{2.0e ⁻³	2.3e ⁻³ }
[Acap][r ^F]	{4.5e ⁻⁴	6.0e ⁻⁴ }	{3.3e ⁻³	4.0e ⁻³ }	{8.8e ⁻³	1.1e ⁻² }

The percentiles are defined as: 25th ∈ [0.001, 0.30], 25th – 75th ∈ [0.30, 3.31], 75th ∈ [3.31, 7210.8]

Keeping in mind the descriptive charts above, we are therefore interested to give some more insights of the features of absorptive capacity and try to identify and elaborate its real effect on productivity of Swedish firms' in the next section.

4. Econometric analysis

The econometric specification is as derived in equation (2.9) is initially estimated as simple productivity model. Thereafter, we extend our analysis of TFP in a stepwise manner by adding the measures of R&D spillovers and absorptive capacities to the own firms R&D. Since our dependent variable TFP is in levels, we confine our attention to the fixed effect estimator since this technique wash out the firm level specific effects inherent in the constructed TFP measure.

Table 3: Dependent variable; logarithm of total factor productivity

Independent variable	FE ⁵	FE	FE	FE	FE	FE
	(mod 1)	(mod 2)	(mod 3)	(mod 4)	(mod 5)	(mod 6)
r^O	6.3E ⁻⁵ (t-1) (0.080)*	7.5E ⁻⁵ (t-1) (0.042)**	6.8E ⁻⁵ (t-2) (0.064)*	6.7E ⁻⁵ (t-2) (0.067)*	6.7E ⁻⁵ (t-2) (0.068)*	6.7E ⁻⁵ (t-2) (0.066)*
log(Tgap)	-	0.01 (t-2) (0.031)**	0.01 (t-2) (0.075)*	0.01 (t-2) (0.022)**	0.01 (t-2) (0.022)**	0.01 (t-2) (0.064)*
log(r^B)	-	0.02 (t-4) (0.434)	0.04 (t-4) (0.233)	0.02 (t-4) (0.585)	0.02 (t-4) (0.424)	0.03 (t-4) (0.332)
log(r^F)	-	0.08 (t-3) (0.030)**	0.09 (t-3) (0.018)**	0.08 (t-3) (0.025)**	0.08 (t-3) (0.027)**	0.09 (t-3) (0.019)**
[Acap][log(Tgap)]	-	-	0.02 (t-3) (0.037)**	-	-	0.02 (t-3) (0.021)**
[Acap][log(r^B)]	-	-	-	0.02 (t-4) (0.000)***	-	0.01 (t-4) (0.760)
[Acap][log(r^F)]	-	-	-	-	0.02 (t-4) (0.000)***	0.01 (t-4) (0.782)
<i>Firm effects</i>	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
<i>Year effects</i>	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
<i>Breusch and Pagan</i>	11753.2***	3957.9***	3866.3***	3767.0***	3775.4***	3638.8***
<i>Hausman - Wu</i>	377.78***	537.95***	188.19***	1676.8***	1608.9***	n.a.
<i>R² adjusted</i>						
-overall	0.41	0.46	0.47	0.45	0.45	0.46
-within	0.75	0.80	0.80	0.80	0.80	0.80
-between	0.29	0.30	0.31	0.29	0.29	0.30
<i>Observations</i>	7618	4101	4080	4121	4121	4078

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

⁵ This specification has also been performed for all firms' including those reported null R&D expenditures, the results do not appear to alter by much.

In table 3 above, we present the econometric results. At first, as a determinant of the rate of innovation and productivity, the effects of own R&D expenditure is found to be significant at 10% level and the size of the parameter estimate seems to be rather stable irrespectively the choice of model. The weak contribution of own R&D intensity may to some extent explains by the fact that those flows does not quite reflects stocks. Approximately 50% of firms' in sample is reported with zeros in R&D and most likely those figures represent substantial measurement errors in the data. By this statement, we focus on firms' which conduct R&D investments strictly larger than zero.

In a productivity 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 consists 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.

As showed in table 3, we include the technology transfer parameter as proxying the spillovers that generated within the own industry. The coefficient of technology transfer is expected to be positive if there exist a catching-ups among firms as discussed in Van Reenen *et.al.* (2000): the lower firms' level of TFP relative to the maximum TFP in a specific industry and year (the more positive value of *T-gap*), the greater the potential for new technologies to be transferred to the non-frontier firm. Results suggest that the relationship between productivity and relative productivity gap is robust and positively significant, indicating existence of technology spillovers and convergence among firms' in the Swedish manufacturing sector. Other studies testing for within industry spillovers by means of constructed R&D spillovers are found in Poldahl (2004), but these do not contribute to the productive growth by Swedish firms'.

Considering local and international spillovers linked to trade flows, our measure of spillovers are computed by using I/O tables and R&D investments at industry level. Innovations introduced in one industry are expected to boost productivity in other industries abroad and within the own country. Our econometric results reveal that domestic between industry R&D spillovers are found to be positive but insignificant in all models, indicating a weak support of

productive spillovers following the I/O links between industries in the Swedish manufacturing, i.e. the innovations generated in other Swedish industries following the deliveries within the I/O linkage fails to explain firms' productivity.

Rent spillovers do not only stem from domestic sources only, international trade and the increasing globalization may also affect the flow of external new knowledge. From the econometric analysis, we can distinguish R&D spillovers stemming from abroad. Our results points at positive and significant contribution from the R&D spillovers from other countries. These results are well in line with other similar studies where R&D spillovers are found to enhance the productivity 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 productivity growth approach (see Grünfeld 2002). This conclusion is also supported in a study (Hanel 2000) of Canadian industry data. Summing up the observations about R&D externalities, results suggest that domestic and international R&D spillovers have more or less similar impact on the Swedish firms' productivity.

In modelling productivity aside classical factors as firms R&D and spillovers, we extend our analysis by including the measure of the firms' absorptive capacity and provide with a short discussion on the role of "two faces of R&D" and its relative influence on Swedish firms productivity performance.

As mentioned in appendix, the terms represent the indirect effects are obvious strongly correlated with each other, our regressions are therefore performed with each term alone and finally as fully model in last the column (see e.g. mod 6). The overall impression from table 3 is that there exist a robust interaction between various kinds of spillovers and absorptive capacity. For example in the third model, the indirect effects through the technology gap is found to be significant and positive at the 5% conventional significant level, indicating existence of each firms' R&D efforts plays a direct and indirect role on the firms productivity performance. Perhaps there exist complementarity's between the own firms R&D activities and spillovers following the relative productivity gap, such as those firms conducting an aggressive research and development strategy itself in general have more potential to learn and exploit the outside knowledge generated by competing firms in the same industry. The

same conclusions also holds in the forth and fifth model, there absorptive capacity is found to interplay well with both domestic inter sectoral- and imported R&D spillovers. As a further note in model 6; we can not reject the hypothesis that those indirect effects discussed above are of the same impact with respect to productivity.

Using the R&D intensity in modelling firm's absorptive capacity had been applied in Karpaty *et.al*, Kinoshita and Reenen *et.al*, studies. This rather straightforward approach has been tested and extensively analysed in our regressions but are not mentioned here. Using this measure of absorptive capacity does not provide with any clear and distinct statistical measurement of the role of "the two faces of R&D".

In the next part of the empirical section, we turn to an investigation of absorptive capacity among low and high productive firm. The idea is to use a percentile regression approach on specification (2.9), 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 efficient test the underlying hypothesis of more productive firms' on average be more efficient in absorbing outside knowledge.

Table 4: Percentile regressions – logarithm of TFP (using within transformed variables)

Independent variable	(mod 7)		(mod 8)		(mod 9)	
	Q10	Q90	Q10	Q90	Q10	Q90
r^O	9.2E ⁻⁵ (t-1) (0.708)	7.4E ⁻⁶ (t-1) (0.976)	1.1E ⁻⁴ (t-1) (0.003)**	3.0E ⁻⁵ (t-1) (0.768)	1.1E ⁻⁴ (t-1) (0.022)**	3.0E ⁻⁵ (t-1) (0.770)
log(Tgap)	0.005 (t-2) (0.443)!!!	0.061 (t-2) (0.000)***!!!	0.01(t-2) (0.424)!!!	0.064 (t-2) (0.000)***!!!	0.006 (t-2) (0.538)!!!	0.065 (t-2) (0.000)***!!!
log(r^B)	-0.04 (t-4) (0.277)	0.004 (t-4) (0.927)	-0.05 (t-4) (0.219)	0.007 (t-4) (0.842)	-0.05 (t-4) (0.082)*	0.011 (t-4) (0.712)
log(r^F)	0.045 (t-3) (0.433)	0.137 (t-3) (0.044)**	0.03 (t-3) (0.656)!!	0.15 (t-3) (0.018)**!!	0.03 (t-3) (0.446)	0.15 (t-3) (0.061)*
[A-cap][log(Tgap)]	0.037 (t-3) (0.007)**	0.064 (t-3) (0.000)***	- -	- -	- -	- -
[A-cap][log(r^B)]	- -	- -	0.008 (t-3) (0.265)	0.007 (t-3) (0.348)	- -	- -
[A-cap][log(r^F)]	- -	- -	- -	- -	0.009 (t-3) (0.318)	0.007 (t-3) (0.440)
<i>Year effects</i>	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
<i>R² adjusted</i>	0.46	0.45	0.45	0.45	0.45	0.45
<i>Bootstrappings</i>	20	20	20	20	20	20
<i>Observations</i>	4152	4152	4192	4192	4192	4192

Note: p-values within brackets. *** ** * indicate significance at 1, 5 and 10% levels respectively. !!! !! ! indicate coefficients in 10th respective 90th percentile are statistical significant different at 1, 5 and 10% levels

At first, there are a few interesting questions appearing in studying the regressions in table 4. Analysing the direct effect of the own firms R&D activities, the picture are not very distinct, we are not able within a percentile regression to discriminate between firm localised near the two percentiles by F-test. Focusing on model 8 and 9, some tendency is in favour of the low productive firms conducting active research investment, otherwise the marginal effects of both groups on the level of productivity are not robust and are difficult to interpret.

Interpreting the set of spillovers comprising of the relative productive gap as well as R&D spillovers a fairly clear pattern appears. Comparing the coefficients of technology gap in the 10th and 90th percentile in all specifications, those are found to be positive and significant different from each other. Interestingly, the process of catching-up is merely verified among the highly productive firms centred on the 90th percentile, not for firms' near the lower percentile limit. No precise pattern is detected when analysing the R&D spillovers through domestic inter sectoral deliveries, apparently the pattern among the low and high percentiles are not distinct and the effects of domestic R&D spillovers obviously not help in explaining productivity. The corresponding spillovers following the deliveries from abroad are found to contribute to the productivity among those representing by the 90th percentile but not in the 10th. The effects of international R&D spillovers are found to be most beneficial to firms near the 90th percentile limit (see mod 8).

The interactions of absorptive capacity give mixed impression, in model 7 our evidence points at existence of positive returns for high- as well low productive firms' in using spillovers within the own industry. These coefficients are significant but they do not appear to be of different size whenever comparing the high and low percentile groups. Otherwise, by using the percentile regression method we do not further reveal any strong evidence of increasing gains accruing to the high productive firms learning from R&D based spillovers.

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 can not predict the future economic shocks; hence any IV models are therefore not given in the econometric section. The econometric specification have also been checked for lag lengths and outliers, the goodness of fit measure (R^2) supports using of long time lags for R&D spillovers and a maximum of 2 lags for R&D intensity. Otherwise, the regressions are found to be rather stable irrespective including influential outliers of R&D intensity or not.

5. Concluding remarks

Results found here suggest that the relationship between firms' R&D efforts and the level of TFP is strong. R&D expenditure seems not only to cause the productivity direct, but also indirect through innovation efforts by competitors and other firms.

Analyzing our measure of spillovers, technology gap as well as R&D spillovers, we find that technology gap is a stable and robust promoter for productivity by Swedish manufacturing firms'. This is an indicating of that non frontier firm will benefit from technology spillovers originated from the innovative leader in a specific industry. The I/O weighted measure of spillovers deriving from trade flows between the domestic industries seems to be a weak promoter of firms TFP, this is not to be expected since innovations in one industry is expected to increase the productivity in other industries as well as other countries (see e.g. Griliches 1995). Assuming that R&D spillovers originate from the deliveries through import from other countries, our evidence suggest that this channel of knowledge dispersion promoting the productivity by firms'.

The fact that productivity not only causes by external new knowledge and firms own R&D investments, the interplay between firms' absorptive capacity and different set of spillovers also contributes. The picture of the two faces of R&D seems to be well depicted in our empirical analysis of the Swedish firms in the manufacturing sector. Firms' that engage actively in R&D, appear to be those that irrespectively the source of knowledge dispersion benefit from the own in-house capability in learning from the competitors.

Further investigating the absorptive capacity behaviour by focusing on low- and high productive firm reveals some persistent feature for the Swedish manufacturing. We are not able to identify any differential indirect effects by comparing low and high productive firms, although the fact that absorptive capacity seems to only work through the release of technology gap spillovers along the low productive firms.

Considering absorptive capacity linked with R&D spillovers, domestic as well as international, our results point at unclear evidence whether increasing benefit to high productive firms really exists. Perhaps they use the external new knowledge most efficient in their production and research and development, but our percentile regressions do not suggest at any support for discriminatory effects between firms representing the 10th and 90th percentiles.

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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 Törnqvist index⁶). Source: Statistics Sweden/Financial Statistics.
2. R&D: Total Research and Development expenditures⁷ 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. Technology gap, maximum TFP for the m th firms in the j th industry. The leading firm is defined at 2 digit sni-92. Source: Statistics Sweden/Financial Statistics.

$$T - gap_{ijt} = \frac{TFP_{mjt}^{max} - TFP_{ijt}}{TFP_{ijt}}, \text{ where } m = \text{leading}$$

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

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

⁶ See Gunnarsson and Mellander (1999).

⁷ 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).

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.

$$r_{jt}^F = \sum_l b_{jl}^F \left(\frac{R \& D}{Y} \right)_t^F$$

7. Absorptive capacity⁸. Source: SCB/Financial Statistics, SCB.

$$A - cap_{it} = \frac{r_{it}^O}{1 + r_{it}^O}$$

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 good producer price index	SCB homepage	Imports
KPI	Aggregated consumer price index	SCB homepage	Wages

⁸ This hyperbolic transformation allows for decreasing returns in R&D activities (see Grünfeld 2002, for further discussions).

Table A2: Correlation matrix[@]

	log(TFP)	r^O	log(T-gap)	log(r^B)	log(r^F)	[A-cap]* [log(T-gap)]	[A-cap]* [log(r^B)]	[A-cap]* [log(r^F)]
log(TFP)	1.0000							
r^O	0.0135	1.0000						
Log(T-gap)	0.0488	-0.0225	1.0000					
log(r^B)	0.1960	0.0239	-0.0081	1.0000				
log(r^F)	0.1705	0.0340	-0.1239	0.4555	1.0000			
[A-cap][log(T-gap)]	0.1176	-0.0057	0.7981	0.0842	0.1187	1.0000		
[A-cap][log(r^B)]	-0.1954	-0.0569	-0.0018	-0.0661	-0.4211	-0.4247	1.0000	
[A-cap][log(r^F)]	-0.1871	-0.0525	-0.0350	-0.1212	-0.2364	-0.4469	0.9578	1.0000

Table A3: Variance decomposition[@]

Variable	Overall standard deviation	Within standard deviation	Between standard deviation
log(TFP)	0.695	0.417	0.639
r^O	75.86	70.98	24.79
log(T-gap)	1.241	0.849	1.053
log(r^B)	0.506	0.138	0.497
log(r^F)	0.928	0.073	0.945
[A-cap][log(T-gap)]	0.831	0.579	0.671
[A-cap][log(r^B)]	1.723	0.744	1.601
[A-cap][log(r^F)]	1.368	0.649	1.265

[@] Note, all zeros in r^O variable are dropped due to consistency with the regression analysis.

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.