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DOMESTIC VS INTERNATIONAL SPILLOVERS: EVIDENCE FROM SWEDISH FIRM LEVEL DATA

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This paper investigates the association between total factor productivity growth and the R&D expenditures of Swedish manufacturing firms in the presence of domestic- and international R&D spillovers. The paper assumes that the principal channel of transmission of new technology is through I/O relations. Econometric evidence suggests that international as well as domestic inter-industry R&D spillovers are important determinants of firms' productivity growth in the long run. The R&D spillovers generated within the industry and following I/O links seem to be of minor importance in explaining productivity growth. It seems likely that within-industry productivity spillovers follow other channels than I/O flows, such as horizontal spillovers through copying of new products and processes, or labour turnover. The use of a convergence parameter is one way to check for such within-industry technology flows. Our results indicate that a catch-up process exists by which the non-frontier firms in the Swedish manufacturing sector absorb knowledge spillovers from the leading firms in the industry. Finally, a firm's own R&D efforts are found to be more or less positively correlated with the TFP growth, maybe the contribution from R&D efforts in some sense are underestimated. [*]

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

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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 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.

Another issue addressed in the paper is the role of domestic versus international productivity spillovers. International spillovers should have become increasingly important because of more trade, increasing access to information technologies across the countries etc. Open economies are assumed to gain from international spillovers of new technology in two ways. First, imports of improved capital equipment, intermediate goods and services enable the importing country to absorb the new technology embodied in goods or services. Second, transmission channels such as foreign direct investments and foreign trade are also important sources of productive knowledge. A small country very open to international trade and investments such as Sweden provides an interesting case for the study of domestic as well as international spillovers.

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 expected results are that productivity growth should be higher in firms with a low initial level of productivity relative to the leading firms in the industry or the industry average.

In this essay, we assume that the potential for inter-sectoral productivity spillovers generated in any sector can be proxied by its level of current R&D expenditures. By regarding these as embodied in the sector's outputs of intermediate goods, new capital goods or commodities for final consumption, we trace their transmission through the economy via I/O flows (see Griliches and Lichtenberg 1984). Therefore we use the national account system to map the aggregate knowledge flows between 22 Swedish manufacturing sectors.

Although there are a lot of studies within this field that apply industry level data, to our knowledge there are few studies trying to model the productivity changes through the I/O trade flows in the Swedish manufacturing firms. This study may also have implications for policy making by generating knowledge about the driving forces behind the productivity processes. Having more knowledge about the innovation structure, there will also be an instrument for politicians to designate the incentive scheme for R&D efforts. Finally, this study can also be expected to enrich the existing literature in this topic.

The main objective of this paper is to evaluate the role of national and international knowledge spillovers for productivity growth. More specifically, we are analysing whether R&D spillovers through the I/O channels affect the TFP growth of firms in datasets covering Swedish manufacturing firms in the period 1990 – 2000 with at least 50 employees.

This paper is organised as follows: In the next section, I will review the underlying dataset for this study. The third section gives a presentation of the theoretical model and discussion of other relevant variables of the TFP growth model. The fourth and fifth sections provide the econometric output and conclusions.

1.2 Literature overview

Surveys of the literature on the estimation of spillovers (Nadiri, 1993, Griliches, 1992) generally conclude that while there is evidence that they raise productivity, estimates of their importance vary greatly across studies. There is variety in the proxies chosen to measure spillovers: R&D expenditures, patent information and innovation surveys have all been used. In addition, different estimates of the technological distance[1] of firms from each other, and of sectors have been used to weight the technology stock (see Jaffe 1986). Coe & Helpman (1995) construct international R&D spillovers by using information from I/O tables for a panel of 21 OECD countries. They estimate a panel regression and found that foreign R&D has a beneficial effect on the domestic productivity. These effects are stronger the more open the economy is to foreign trade. Likewise, a study of the Norwegian business sector by Grűnfeld (2002) also confirmed that international spillovers constitute an important channel of R&D knowledge. He also tried to explain 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 of domestic as well as imported R&D spillovers but no such spillovers through foreign direct investments. The absorption effect amplifies the productivity imports are concerned, but no such effects come through domestic intermediaries.

There are also a few Swedish studies investigating the spillovers within an I/O framework. Ejermo (2001), analyses the productivity spillovers of R&D for a cross section of Swedish industries in 1997. He compares the difference between I/O techniques and a "technological closeness" approach and found that they are weakly correlated. Otherwise, the cross sectional framework does not show significant spillovers across the industries.

[1] The smaller the distance (geographical and/or technological) from an innovative firm, the larger the amount of received spillovers and therefore the higher the growth rate of the knowledge stock of a firm/industry, which implies a higher growth rate of productivity (see Caniels 2000).

A slightly different approach in modelling spillovers is described and analysed in Hanel's (2000) paper about the Canadian manufacturing sector. He assumes that spillovers come through the transmission of new technology embodied in the foreign direct investments processes. Three original proxies are applied, information on patenting, the size and the origin of foreign ownership in the host country and the R&D expenditures in the country of origin. His econometric results suggest that the domestic inter-industry spillovers are the leading indicator of the TFP growth. All three measures of international spillovers contribute positively and significantly to the TFP growth, however the international counterpart is found to be of minor importance compared to the domestic sources.

Several authors (Mohnen, 1992 and Bernstein & Mohnen 1998) argue for the fact that the stock of R&D in a given industry in country B has an effect on TFP growth in the same industry in the receiver countries; they let the data determine the nexus between productivity and the stock of foreign R&D. Wolfgang Keller has in a number of papers (see e.g. Keller 1997, 2000, 2002a, 2002b) studied both national and international technology spillovers. In short, his results indicate robust evidence on the existence of technology spillovers.

Some of the reviewed studies are based on pure aggregated data, such as industry- or macro level. Caution needs to be taken in making comparisons between the contributions from R&D spillovers measured at different levels of aggregation. The contribution from the R&D spillovers in industry/macro studies may be affected by aggregation bias.

2. 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 2000[2]. *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 convering 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 industry (see SCB, homepage http://www.scb.se). Table 1 reveals a tremendous variation in the R&D[3] intensity among industries. The most R&D intensive industry (communication) spent in 1999 50 percent of value added on R&D while the corresponding figure for "publishers and printers" was about 0.2 percent. Obviously, the importance and impact of a policy intended to affect firm R&D may be very different in different industries.

Table 1: R&D intensities by industry, 1999.

SNI 92	Industry	R&D intensity	SNI 92	Industry	R&D intensity
15	*Food*	*1.5%*	*26*	*Non mineral products*	*4.3%*
16	*Tobacco*	*5.2%*	*27*	*Basic metals*	*4.5%*
17	*Textiles*	*3.7%*	*28*	*Metal products*	*2%*
18	*Clothing*	*0.2%*	*29*	*Machinery and equipment*	*13.6%*
19	*Leather*	*1.4%*	*30*	*Computer*	*27.4%*
20	*Wood and furniture*	*0.5%*	*31*	*Electrical machinery*	*9.9%*
21	*Pulp and paper*	*3.4%*	*32*	*Communication*	*51.2%*
22	*Publishers and printers*	*0.2%*	*33*	*Medical, precision and ..*	*31.2%*
23	*Refineries*	*4.7%*	*34*	*Motor vehicles*	*24.3%*
24	*Chemicals*	*39%*	*35*	*Other transport equipment*	*10.9%*
25	*Rubber and plastic*	*4.1%*	*36*	*Other manufacturing*	*3.4%*
Total number of observations, (firms with R&D>0) 1108					

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

[2] 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.
[3] The R&D measure from Financial Statistics is reported with zeros for more than 50% of observations.

3. Theoretical framework

The total value of sales in each firms at time *t* is produced with skilled labour (*S)* and unskilled labour (*U*), physical capital *(K)* and intermediate goods *(M)* according to the standard neoclassical production function:

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

Where A is an index of technical efficiency or total factor productivity (TFP). The dependent variable is the growth rate in total factor productivity (ΔlogTFP). The growth in TFP may be obtained by means of the Törnqvist[4] index (see Gunnarsson and Mellander, 1999; Harper, Berndt and Woods, 1989). The Törnqvist TFP index is simply the difference between the growth in Y and the growth in a Törnqvist input quantity index X:

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

Where Δ is the difference, defined such that $\Delta \ln X_t = \ln X_t - \ln X_{t-1}$ and

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

The $\overline{w}_{jkt}$ are weights defined in terms of average cost shares according to

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

Where P_k is price of input k. Where t, t=1,…,T indexes time, i and, i = 1,..., N denotes firms, j and j = 1,…, J denotes industries. In equation (2.1) above, Y_{it} is deflated sales,

[4] The Törnqvist index builds on a generalisation of a Cobb Douglas production function (see Coelli, Rao and Battese 1998).

$X_{it} = (U_{it}, S_{it}, M_{it}, K_{it})$ is the employment of unskilled – and skilled workers, inputs of deflated raw materials and energy and, deflated book value of capital stocks.

Table 2: Summary statistics

Year	Number of firms	TFP growth Mean	Standard deviation	Min	Max
1991	1583	-0.013	0.14	-1.58	1.20
1992	1488	0.003	0.18	-1.58	3.25
1993	1372	0.030	0.15	-1.51	1.80
1994	1366	0.052	0.14	-1.48	1.61
1995	1412	-0.014	0.15	-1.21	2.50
1996	1495	-0.026	0.17	-2.57	1.30
1997[5]	1522	0.34	0.34	-1.51	3.38
1998	1551	0.0001	0.25	-4.32	2.58
1999	1576	0.017	0.21	-2.35	2.15
2000	1482	-0.004	0.23	-2.46	2.38
	Total 14847 observations and 5672 unique firms	0.038*	0.23*	-4.32*	3.39*

* refers to the whole period.

Inspecting table 2 above, the growth in total factor productivity shows a high fluctuation over time as well as large variation across firms.

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 Griffith, Redding and Van Reenen 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:

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

[5] Probably the reason behind the average productivity growth rise of 34% in 1997 is the drastic decline in energy prices during 1996 - 1997.

Where η = (dA/dG)· (G/A) is the elasticity of TFP with respect to the R&D knowledge stock (G) and ν = (dA/dB) · (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 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 ρ = 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):

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

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 theoretical motivation of the R&D effect is provided by the theory of endogenous innovation and growth e.g. (Aghion & Howitt (1992), and Romer (1990)).

The residual set of influences B may be regarded as knowledge capital stocks 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 from the different sectors. The knowledge capital stocks may also be generated by the technological transfer between firms, for instance non-frontier firms may gain from the technological leader in the economy. 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 levels of a firm's own TFP, since TFP in a non-frontier firms lies behind the leader, the coefficient of TFP is negative (Reenen et.al. 2000). Hence, ΔlnB_{jt} can be approximated by the I/O weighted R&D spillovers and the measure of technological transfer:

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

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 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 **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 formulae:

”*Within-industry spillovers”:*

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

“*Between-industry R&D spillovers”:*

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

”*International R&D spillovers”:*

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

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:

$$\Delta ln A_{ijt} = \alpha_1 ln A_{ijt-1} + \alpha_2 ln r^O_{ijt-s} + \alpha_3 ln r^W_{ijt-s} + \alpha_4 ln r^B_{jt-s} + \alpha_5 ln r^F_{jt-s} \quad (2.11)$$

where j is the industry using spillovers, α_i are empirically determined parameters identifying the effective contribution of within/between industry and international spillovers and the firms' own R&D activities. The measure of productive knowledge is therefore a function of the firms' own R&D efforts (r^O = *R&D/Y)* and of the R&D spillovers, stemming from domestic industries, r^W (within industries) and r^B (between industries), and from abroad r^F.

Studying data we note that some interesting findings appear. In table 3 we can see that industries with the highest ranking of domestic R&D weighted input-output spillovers are not widely different form the highest ranking of international R&D weighted input-output spillovers. Some exceptions are the "rubber and plastic" industry, which seems to absorb most R&D knowledge flows from the domestic sources but does not receive as much from the international part. Also evident in comparing table 1 and 3, the most R&D intensive industries receive a lot of external knowledge from other sectors[6].

Table 3: Domestic vs. international spillovers year 1999

Top ten rankings of "International R&D spillovers" (defined at 2 digit industry level)		***"Domestic R&D spillovers"***	
Communication	**2.7%*	*Rubber and plastics*	*0.70%*
Medical, precision and optical	*1.7%*	*Computer*	*0.44%*
Other transport equipment	*1.6%*	*Electrical machinery*	*0.43%*
Computer	*1.3%*	*Other manufacturing*	*0.41%*
Rubber and plastics	*1.3%*	*Metal products*	*0.32%*
Motor vehicles	*1.2%*	*Other transport equipment*	*0.29%*
Chemicals	*1.1%*	*Publishers and printers*	*0.28%*
Electrical machinery	*1.0%*	*Refineries*	*0.27%*
Machinery and equipment	*0.7%*	*Machinery and equipment*	*0.26%*
Textiles	*0.7%*	*Non mineral products*	*0.26%*

* The figures may be interpreted as percentages. Domestic and international spillovers follow formulas 2.9 and 2.10 respectively (see above).

[6] The partial correlations between the research intensity and domestic as well as international spillovers are 1% and 18% respectively.

3.1 Control variables

The presence of MNE is important for the generation of new technology. The firms within an MNE network can exploit the fruits of their R&D investments at home as well as abroad. Technological advance is in some sense a public good within the MNE, and can also be utilized in foreign affiliates (Fors and Svensson, 1994; Dunning, 1988). By using the information on firms' export behaviour, we capture the MNE in Swedish manufacturing by constructing a dummy variable D_M (see appendix for more definitions). In this fashion, we have an opportunity to discriminate the effects of international R&D spillovers in MNE versus non MNE on the productivity growth in Sweden.

The true contribution from the return to scale economies may be unclear whenever using the Törnqvist productivity index in (2.2). Therefore we have included a scale parameter, 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 determinants 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). Assuming that there is a linear relationship between variables in the models, the empirical equation will have following specification (equation 2.12):

$$\Delta \ln TFP_{ijt} = \alpha_0 + \alpha_1 \ln TFP_{ijt-1} + \alpha_2 \ln r^{O}_{ijt-s} + \alpha_3 \ln r^{W}_{ijt-s} + \alpha_4 \ln r^{B}_{jt-s} + \alpha_5 \ln r^{F}_{jt-s}$$
$$\alpha_6 D_{M\,ijt-s} \ln r^{F}_{jt-s} + \alpha_7 D_{M\,ijt} + \alpha_8 \ln Scale_{ijt} + \alpha_9 \ln H_{jt} + \varepsilon_{it} \qquad \varepsilon_{it} \sim iid(0,\ \sigma^2_{\varepsilon})$$

4. Empirical results

In this section we turn to the results and make inferential statements based on model (2.12) in the previous section. Before we turn to the results, a comment on the estimation is in order. First, specification (2.12) is estimated by FE to check for the basic relationship between productivity growth and R&D spillovers. Thereafter the models in column (1) – (2) are revised in order to model the dynamic productivity effects and account for convergence.

Table 4: Determinants of growth of TFP of Swedish manufacturing firms 1990-2000

	Mod 1	Mod 2	Mod 3	Mod 4
Variables	**FE**	**FE**	**GMM**	**GMM**
log(TFP)	- -	- -	-0.69 (t-1) (0.000)***	-0.64 (t-1) (0.000)***
log(r^O)	0.009 (t-2) (0.031)**	0.010 (t-2) (0.015)**	0.007 (t-2) (0.410)	0.006 (t-2) (0.532)
log(r^W)	0.006 (t-2) (0.439)	0.004 (t-2) (0.609)	0.026 (t-3) (0.060)*	0.012 (t-3) (0.444)
log(r^B)	0.042 (t-1) (0.028)**	0.046 (t-1) (0.015)**	0.148 (t-3) (0.001)***	0.178 (t-3) (0.000)***
log(r^F)	0.041 (t-3) (0.073)*	0.039 (t-3) (0.091)*	0.118 (t-1) (0.022)**	0.095 (t-1) (0.063)*
D_M	0.007 (t) (0.523)	0.009 (t) (0.440)	0.017 (t) (0.338)	0.023 (t) (0.218)
log(r^F)D_M*	0.002 (t-1) (0.404)	0.002 (t-1) (0.328)	0.006 (t-2) (0.224)	0.001 (t-1) (0.763)
log(Scale)	- -	-0.069 (t) (0.000)***	- -	0.055 (t) (0.094)*
log(H)	- -	0.013 (t) (0.104)	- -	-0.006 (t) (0.613)
Year effects	Yes***	Yes***	Yes***	Yes***
Firm effects	Yes	Yes	Yes	Yes
Breusch Pagan	25.71***	21.45***	-	-
Hausman - Wu	66.34***	165.58***	-	-
Sargan test	-	-	126.6***	121.9***
AR(2) test	-	-	-2.20**	-1.53
R^2 adj.				
-overall	0.30	0.23	-	-
-within	0.38	0.39	-	-
-between	0.13	0.08	-	-
No. obs	4550	4474	2322	2182

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

In table 4 above, we present the econometric output. From the regression analysis in column (1) – (4); we are able to investigate the hypothesis that the rate of growth of TFP is increasing with firms' R&D investment. The estimated regression coefficient is equal to 0.01 in model 2 and significantly larger than zero, rejecting the null hypothesis of no association between firms' own R&D efforts and growth of TFP. The positive estimate of R&D parameter will serve as an indication of positive returns on R&D investments of Swedish firms in the manufacturing sector.

The estimated return to R&D is in line with similar studies on these topics. Odagiri (1983) found an estimate of rates of return to research in the range of -0.47 – 0.26 of 370 firms in Japan, whereas Link (1983) found an elasticity equal to 0.06 of 302 firms in the US for the period 1975 to 1979.

For productivity growth, not only firms' own R&D but also outside knowledge is also 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. As argued above, trade may be closely related to rent spillovers (Griliches, 1979). Rent spillovers may be transmitted domestically, within or between industries, or imported from abroad. We will analyse all of these three channels for rent spillovers.

Our regression analysis of rent spillovers reveals an interesting pattern. Innovations introduced in one industry are expected to increase productivity in other industries in other countries as well as within the home country, through a combination of rent and knowledge spillovers. By using the firm level data, we are able to identify that R&D spillovers have a robust impact on total factor productivity growth. In interpreting the results, for simplicity we confine our attention to the GMM in column (4) since this is probably one of our most valid estimators. The coefficient of the international R&D spillovers is equal to 0.095 in the fourth model, indicating that Swedish firms' productivity growth will increase by 9.5 %, all other things being constant, when the international pool of knowledge expands by 1 %. In comparison with similar studies, the positive returns on spillovers received from international source were also found in previous Norwegian studies based on similar methodologies (see Grűnfeld 2002). This conclusion is also supported in a study (Hanel 2000) of Canadian industry data. However, for cross national technology transfers, multinational firms (MNEs) play an important role. It is plausible to argue that a multinational firm has a closer relation to its affiliated partner firms in other countries. Empirical studies have showed that 83 % of the industrial R&D expenditures were attributed to the Swedish MNE (see Fors, 1996). It is therefore plausible to expect international spillovers to be stronger within MNE than outside the network. Our regression analysis does not confirm this hypothesis; hence there is no evidence for stronger knowledge spillovers between firms in MNE with respect to international spillovers.

Following the discussion above considering rent spillovers, we have the conclusion from table 4 that spillovers from abroad are more or less significant. Rent spillovers do not only stem from international trade, domestic inter- and intra industry trade may also be important. Having data on R&D spillovers in Sweden, we are able to draw conclusions and compare with international spillovers. From our results, the domestic between-industry R&D spillovers reveal a coefficient value of 0.18, indicating that if input-output adjusted R&D flows from other sectors increase by one percent, ceteris paribus, the expected productivity growth rises by 18 percent. The within-industry spillover is shown to be significant in 1 out of 4 models, probably indicating that productivity growth is not explained by the I/O weighted R&D spillovers within a specific industry. There may be more factors than I/O flows that determine the total volume of knowledge flows within the industry, there are probably other spillovers such as horizontal- and technological spillover 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 process will give rise to productivity convergence between firms. In contrast to Van Reenen et. al (2000), we employ lagged TFP levels as a measure of catching up. The convergence parameter is found to be negative and significant in specifications 3 and 4 in table 4. The negative estimates reveal robust evidence of productivity convergence among Swedish firms. However, incorporating the technological transfers in a GMM framework apparently causes the contribution from firm's own R&D to disappear.

Summing up the observations about innovations and R&D externalities, results suggest that domestic and international R&D spillovers have similar impact on the Swedish firms' productivity growth. The regression analysis also suggests that domestic and international spillovers have more effect on productivity growth than a firm's own R&D efforts. This may be due to the potential of complementarities between firms' own innovation efforts and knowledge externalities, i.e. maybe R&D spillovers are more productive provided that each of the firms conduct intensive research activities themselves.

To conclude the empirical section, it is in order to give a brief discussion of the control variables. Having checked for firm size effect, the picture from model 2 and 4 is most likely a tendency in favour of a negative relationship between the scale effect and productivity growth, i.e. small firms tend on average to have a comparative advantage over large firms in a productivity 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 – 10000 where a value of 10000 indicates a situation of monopoly. The output from regressions in the second and fourth models reveals an insignificant effect with respect to market concentration on productivity growth.

Robustness of results

Studies by Cohen & Levinthal (1989), Scherer (1984) and Gustavsson & Poldahl (2003) have shown that R&D expenditures at firm level are found to be endogenous. Variables such as firm size, product market competition and production structure, technological opportunity and technological spillovers are all assumed to affect firms' propensity to perform R&D. Shocks to the economic environment can certainly feedback into firms' R&D planning. Rather, we assume that current shocks do not influence past levels of R&D. Consequently, we do not show any IV estimations on the weak exogenous R&D variable[7].

Our results in table 4 have been tested for robustness in lag length. This exercise reveals that the parameter estimates are very sensitive to the choice of a given lag structure. Applying a polynomial distributed lag model indicates that effects of spillovers and

[7] In an earlier version of this essay, we performed IV estimations to check for the consistency problem in R&D intensity. The picture does not seem to alter by much.

each firm's R&D intensity occur with many time lags. Another goodness of fit measure (R^2) supports the same argument in favour of long time lags in our econometric model.

5. Concluding Remarks

Our econometric evidence in this essay suggests that the relationship between firms' R&D efforts and the growth of TFP is weak. Whether or not R&D efforts cause growth through innovation is not obvious. Otherwise, the private returns on R&D investment are found to be in line with similar studies in this area.

Analysing R&D spillovers, we find that domestic and international R&D spillovers have the same effects on TFP growth at the Swedish firm level. The fact that Sweden is a small open economy might explain why the returns from the dissemination of technology from imports of intermediate products have relatively strong effects on the TFP growth. The I/O weighted measure of spillovers within the domestic industry fails to explain the productivity evolutions of the firms. In this context, technological diffusion between firms in the same industry seems to follows other channels than I/O flows. Other studies (see e.g. Karpaty & Lundberg, 2003) point at substantive horizontal spillovers within a region and the presence of foreign owned firms, which might be very important in this respect.

From a policy point of view it is interesting to know whether subsidies for firms' R&D should be given or not. A fair deal of R&D spillovers are transmitted by trade in intermediate inputs and in capital goods. Those goods incorporate the latest technology developments. Hence, it pays for a country to trade with the outside world instead of pursuing an import substitution strategy. Also, the Swedish government should be strongly encouraged to support the R&D investments made by the Swedish firms. Reformation in the labour market in order to attract highly skilled workers and foreign firms with a high level of technological skills into the Swedish market would perhaps give long term economic growth.

There is a need for further studies evaluating the effects of the domestic spillovers on a more disaggregated set of I/O tables. Some problems appear in the use of I/O flows that do not take into account heterogeneous behaviour for all firms in the same industry, for example some firms in an industry might buy their inputs from the domestic suppliers only, and others only from abroad. Our approach could not accommodate for this and we are well aware of this drawback; we are merely trying to evaluate the R&D spillovers within an aggregate I/O set up. There is also an interest in making inferences based on the absorptive capacity of the firms in high tech industries in Sweden. The spillover effect tends to be amplified depending on whether a particular firm carries out a lot of research itself.

6. References

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Appendix

Table A1: Variable definitions:

VARIABLE	*DESCRIPTION*
TFP	*Total factor productivity.* *Source: Statistics Sweden/Financial Statistics.*
r^O	*R&D intensity, 1990 constant prices.* *Source: Statistics Sweden/Financial Statistics*
r^W	*Within-industry R&D spillovers, derived by I/O tables, computed at 2 digit level.* *Source: SCB/Financial Statistics and SCB/National accounts.*
r^B	*Between industry R&D spillovers, derived by I/O tables, computed at 2 digit level. Source: SCB/Financial Statistics and SCB/National accounts.*
r^F	*International R&D spillovers, derived by international I/O tables, computed at 2 digit level. Source: SCB/Financial Statistics, SCB/National accounts and ANBERD.*
D_M	*Dummy variable, 1 = Multinational firm 0 = otherwise.* *Source: Statistics Sweden/Financial Statistics.*
H	*Herfindahl index – market concentration.* *Source: SCB/Financial Statistics.*
Scale	*Scale elasticity parameter.* *Source: Statistics Sweden/Financial Statistics.*

Table A2: Deflators:

DEFLATOR	*DESCRIPTION*	*SOURCE*	*VARIABLES*
PPI	*Aggregated producer price index*	*SCB homepage*	*R&D*
PRODINDEX	*Disggregated producer price index*	*SCB homepage*	*Output and value added*
ITPI	*Disaggregated intermediate goods producer price index*	*SCB homepage*	*Intermediate goods and raw materials*
EPI	*Aggregated energy producer price index*	*SCB homepage*	*Energy*
BYGGINDEX	*Disaggregated construction producer price index*	*SCB homepage*	*Capital stocks of buildings and construction*
MASINDEX	*Disaggregated machinery producer price index*	*SCB homepage*	*Capital stocks of machinery and inventory*
IMPINDEX	*Disaggregated imported good producer price index*	*SCB homepage*	*Imports*
KPI	*Aggregated consumer price index*	*SCB homepage*	*Wages*

Table A3: Summary statistics for each variable

	n	min	max	E(X)	σ	kurtosis	skewness
Δlog(TFP)	14847	-4.32	3.39	0.038	0.23	47.2	1.06
log(TFP)	17734	-1.77	8.07	2.27	0.79	5.95	0.06
r^O	18353	0	72.1	0.018	0.54	17760.8	132.3
$log(r^O)$	8376	-11.45	4.28	-4.6	1.6	2.8	-0.2
r^W	18416	0	6.13	0.004	0.067	5530.9	69.6
$log(r^W)$	18355	-14.5	1.81	-7.05	1.45	3.79	-0.35
r^B	20153	0.0007	0.15	0.007	0.02	27.1	4.6
$log(r^B)$	20153	-7.3	-1.9	-5.9	1.05	6.8	1.9
r^F	20153	0.0009	0.03	0.006	0.005	7.1	1.7
$log(r^F)$	20153	-7.05	-3.5	-5.5	0.9	1.95	-0.02
D_M	20153	0	1	0.23	0.42	2.65	1.28
log(H)	19986	4.98	9.21	6.15	0.95	3.35	0.92
log(Scale)	20153	-2.99	4.56	-0.60	0.95	4.01	0.78

Table A4: Correlation matrices

	Δlog(TFP)	log(TFP)	$log(r^O)$	$log(r^W)$	$log(r^B)$	$log(r^F)$	D_M	log(H)	log(Scale)
Δlog(TFP)	1.0000								
log(TFP)	0.1857	1.0000							
$log(r^O)$	0.0377	0.2327	1.0000						
$log(r^W)$	0.0252	0.0550	0.3232	1.0000					
$log(r^B)$	0.0044	0.2735	0.2580	-0.0676	1.0000				
$log(r^F)$	0.0396	0.2234	0.4960	0.5830	0.5183	1.0000			
D_M	0.0561	0.0890	0.3132	0.1977	0.1068	0.2546	1.0000		
log(H)	0.0437	-0.0533	0.1611	0.4720	-0.1609	0.4335	0.0761	1.0000	
log(Scale)	0.0169	0.0273	0.1119	-0.1808	0.0427	-0.0733	0.2370	-0.1478	1.0000

Table A5: Variance decomposition

Variable	Overall standard deviation	Within standard deviation	Between standard deviation
Δlog(TFP)	0.23	0.21	0.14
log(TFP)	0.77	0.29	0.78
$log(r^O)$	1.60	0.68	1.50
$log(r^W)$	1.45	0.48	1.43
$log(r^B)$	1.04	0.89	0.61
$log(r^F)$	0.91	0.15	0.90
log(H)	0.95	0.63	0.76
log(Scale)	0.95	0.26	0.89

Variable construction

Below, formulae of control variables are given.

1. Market concentration:

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

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

$$Scale\ parameter,\ Scale_{ijt} = \frac{employees_{ijt}}{N^{-1} \sum_{i=1}^{N} employees_{ijt}}$$