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IMPACT OF R&D ON PRODUCTIVITY –

FIRM-LEVEL EVIDENCE FROM FINLAND

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ABSTRACT: This study analyses how R&D expenditure impacts the productivity of companies. We analyse the productivity impact of R&D using a large panel dataset of Finnish firms over a nine-year period from 1996 to 2004. Our results are two-fold. In the short run (in 1-2 years) we find no statistically significant productivity impact of R&D. However, R&D does have an economically and statistically significant impact when we take into account R&D efforts made 3-5 years before. Hence, a window of almost 5 years is needed to capture the productivity impact of R&D.

KEY WORDS: R&D, research and development, dynamic, productivity, lag, long run.

JEL: H25, O32 and 038

ALI-YRKKÖ, Jyrki and **MALIRANTA**, Mika. **T&K-TOIMINNAN VAIKUTUS TUOTTAVUUTEEN – YRITYSTASON ANALYYSI SUOMALAISELLA AINEISTOLLA.** Helsinki, ETLA, Elinkeinoelämän Tutkimuslaitos, The Research Institute of the Finnish Economy, 2006, 20 s. (Keskusteluaiheita, Discussion Papers; ISSN 0781-6847; no. 1031).

TIIVISTELMÄ: Tässä tutkimuksessa tarkastellaan tutkimus- ja tuotekehitystoiminnan (t&k) vaikutusta yritysten tuottavuuteen. Aineistona käytetään laajaa yritystason paneliaineistoa vuosilta 1996-2004. Analyysin tulokset ovat kaksitahoiset. Lyhyellä aikavälillä t&k-toiminnalla ei näytä olevan tuottavuusvaikutuksia, jotka olisivat tilastollisesti merkitseviä. Tämä tulos muuttuu merkittävästi, kun analyysissä otetaan huomioon 3-5 vuotta sitten tehty t&k-toiminta. Tällöin t&k-toiminnalla on selvä tilastollisesti ja myös kokoluokaltaan merkittävä tuottavuusvaikutus. Tulosten mukaan kestää siis noin kolmesta viiteen vuotta ennen kuin t&k-toiminta näkyy yritysten tuottavuudessa.

AVAINSANAT: t&k, tutkimus ja tuotekehitys, dynaaminen, tuottavuus, viive, pitkäaikainen.

JEL: H25, O32 ja 038

1 INTRODUCTION

In relative terms, Finland is among the leading countries investing in research and development (R&D). In 2003, Finland spent 3.4 % of GDP on R&D, while the U.S and Japan spent 2.6 and 3.15 %, respectively. However, the higher R&D expenditure is only a sign of greater input in innovation activities but it says nothing about the output of these efforts.

In this study, we are interested in the impact of R&D on productivity. Using a unique dataset of Finnish firms, we estimate the R&D elasticity of output. Previous panel data studies concerning R&D productivity in Finland have typically reported R&D elasticity varying between 0.02 and 0.08. Husso, Leppälahti and Niininen (1996) estimated the production function by using a sample of 74 firms in 1987-1993. They found that the R&D elasticity was 0.08 and statistically significant. Lehtoranta (1998), in turn, reports R&D elasticity of 0.06. Lehto (2000) used a large sample consisting of more than 11, 000 observations to estimate the R&D elasticity. The author found that the R&D elasticity was positive varying between 0.02 and 0.06. Instead of the R&D elasticity, Maliranta (2000) estimated the rate of return of R&D by using a sample with more than 4700 observations. In most his estimations, the coefficient of R&D was not statistically significant.

However, the results of the above-mentioned studies are based on static models. In contrast, our purpose is to study the impact of R&D on productivity in Finland by employing a dynamic production function similar to the approach by Bond, Harhoff and Van Reenen (2002). They used this approach to compare the R&D elasticity of output in Germany and the UK.

The goals of this study are two-fold. *First*, we estimate the impact of R&D on output in Finland by applying the same model as Bond *et al* (2002). The caveat of this model is that it takes into account the potential productivity effects of R&D dated t and t-1. Implicitly, it may take a substantially longer time before investment in R&D turns to productivity improvement. This thought motivated our second goal related to the longer run effect of R&D. To take into account these longer run effects, we proceed step by step by adding more lagged R&D variables to the model. The remainder of the paper proceeds as follows. Section 2 includes the description of the data. Section 3 gives an empirical analysis, main results and robustness tests. As a final sensitivity check, we use an alternative dataset to confirm our results. Finally, Section 4 contains a summary and concluding remarks.

2 DESCRIPTION OF THE DATA

Our data is a unique company-level dataset consisting of Finnish companies operating in different industries. Two separate data sources have been merged. The information of R&D expenditure is based on an investment survey conducted by The Confederation of Finnish Industries. To this data, we have added the information of companies' financial statements provided by Balance Consulting Ltd.

Our unbalanced panel data consists of 434 companies with varying time series[1]. Companies with 5 or less observations available are excluded from the sample, thus our data includes only those companies with at least 6 annual observations.

Table 3.1 presents descriptive statistics for sample firms. Mean and median turnovers are Eur 454 million and Eur 36 million, respectively. In terms of employment these firms had, on average, 1720 employees.

Table 2.1. Descriptive statistics

	Number of observa-tions	Mean	Standard Deviation	Median	Mini-mum	Maximum
Value added, (EUR. mill.)	2379	139.90	673.83	12.03	0.12	12065.74
Net Sales, (EUR. mill.)	2379	454.16	2212.81	36.24	0.39	41250.47
Capital stock, (EUR. mill.)	2379	295.21	1365.62	12.64	0.07	15700.04
R&D, (EUR. mill.)	2379	14.95	160.37	0.70	0.00	3618.86
R&D capital stock, (EUR. mill.)	2379	57.58	514.93	3.44	0.00	13833.88
Employment	2379	1719.51	5503.24	229	3	60289
Non-R&D employment	1034	2232.46	6195.26	301.50	12	43882
R&D employment	1038	170.71	1418.64	7	0	20722

[1] To control the potential bias caused by outliers, we employed the method of Hadi (1994) to identify and exclude outliers.

3 ECONOMETRIC SPECIFICATION

We consider the Cobb-Douglas production function following closely the model by Bond, Harhoff & Van Reenen (2002).

$$y_{it} = \beta_n n_{it} + \beta_k k_{it} + \beta_r r_{it} + (\eta_i + \upsilon_{it} + m_{it}) \tag{1}$$

$$\upsilon_{it} = \rho \upsilon_{i,t-1} + e_{it}$$

$$e_{it}, m_{it} \sim \text{MA}(0)$$

where y_{it} is log production of company *i* in year *t*, n_{it} log employment, k_{it} log capital stock, r_{it} log some measure of R&D inputs and α_t a year-specific intercept. η_i represents an unobserved firm-specific effect, υ_{it} a possibly autoregressive shock and m_{it} serially uncorrelated measurement errors.

The model can be rewritten in the following dynamic representation:

$$y_{it} = \beta_n n_{it} + \rho\beta_n n_{i,t-1} + \beta_k k_{it} + \rho\beta_k k_{i,t-1} + \beta_r r_{it} + \rho\beta_r r_{i,t-1} + \rho y_{i,t-1} \tag{2}$$

$$+ (\alpha_t - \rho\alpha_{t-1}) + (\eta_i(1-\rho) + e_{it} + m_{it} - \rho m_{i,t-1})$$

or

$$y_{it} = \pi_1 n_{it} + \pi_2 n_{i,t-1} + \pi_3 k_{it} + \pi_4 k_{i,t-1} + \pi_5 r_{it} + \pi_6 r_{i,t-1} + \pi_7 y_{i,t-1} + \alpha_t + (\eta_i + w_{it}) \tag{3}$$

subject to three unlinear common factor restrictions $\pi_2 = -\pi_1\pi_7$, $\pi_4 = -\pi_3\pi_7$ and $\pi_6 = -\pi_5\pi_7$. These common factor restrictions can be imposed and tested using minimum distance techniques.

Our estimation strategy proceeds as follows. First, we estimate the unrestricted version of the equation and use a minimum distance estimator to obtain the structural parameters. If the restrictions are rejected by the data, we use the parameters of the unrestricted version and calculate the corresponding long run effects. Then we proceed by considering whether the impact of R&D differs between high tech and low tech industries. We also expand the basic model by adding more lagged R&D variables to the regression. Finally, we use alternative specifications and data to examine if our results are robust.

In addition to standard OLS, we estimate the model by a standard first differenced GMM estimator (DIF) proposed by Arellano and Bond (1991). However, this estimator is found to have poor finite sample properties when the marginal processes for input factors are highly persistent (Blundell and Bond 1998). In these cases, the lagged levels of series are only weakly correlated with subsequent first-differences. By exploiting the extended set of moment conditions, Blundell and Bond derived a linear estimator labelled the GMM system estimator (SYS).

a. The basic results

Our basic results are contained in Table 3.1. Following Bond *et al* (2002), we estimate equation (3) by OLS, Within groups, Difference GMM and System GMM estimators. In the upper part of the table, we report the results of the unrestricted version of the model. We tested common factor restrictions but these restrictions are rejected in all estimations except in the DIF3 estimation[2]. Hence, equation (3) is treated as an unrestricted model and consequently corresponding long-run effects and standard errors are computed and reported in the lower part of the table[3].

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[2] We imposed common factor restrictions with minimum distance estimation and tested these restrictions. In OLS, Within Groups, DIF2, SYS2 and SYS3 estimations restrictions were rejected at better than 0.01 level. The detailed p-values of these tests and structural parameters of restricted models can be found in Appendix (Table A.1).

[3] In order to consider longer-run effects, we used a non-linear combination of estimators. The point estimate of interest is obtained by:

$$\hat{\beta}_{RD(long.run)} = \frac{\sum_{k=0}^{n} \hat{\beta}_{RD(t-k)}}{(1-\hat{\beta}_{y(t-1)})}$$

Table 3.1. Basic results (Dependent variable=log (value added))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Value added (t-1)	.75349*** (.021338)	.2215774*** (.035279)	.3825919*** (.0554548)	.3303431*** (.1238899)	.5344932*** (.04965)	.56434*** (.076295)
Capital (t)	.1021865*** (.033824)	.049445 (.032754)	-.0469065 (.128)	.0151752 (.1321912)	.0347964 (.1237187)	.289844** (.134332)
Capital (t-1)	-.0475466 (.0334627)	.0025298 (.0352704)	.0312099 (.084708)	-.0222855 (.0994217)	.0191046 (.0987529)	-.13905 (.109737)
Employment (t)	.66464*** (.068508)	.67549*** (.06828)	.8100222*** (.1213321)	.816071*** (.1311999)	.7474402*** (.115134)	.814581*** (.106914)
Employment (t-1)	-.495973*** (.0677018)	-.115078* (.065794)	-.2496686** (.1019975)	-.253172* (.1500899)	-.382018*** (.114404)	-.55536*** (.123594)
R&D (t)	.0043114 (.0088615)	0017498 (.010564)	-.0361816 (.0311366)	-.0190799 (.0421365)	-.014715 (.0310852)	-.021988 (.033539)
R&D (t-1)	.0222587** (.0091218)	.00485 (.01021)	.0231161 (.025358)	.0314241 (.0279242)	.0445097* (.0255098)	.052233** (.025863)
m1 (p-value)			<0.001	<0.001	<0.001	<0.001
m2 (p-value)			0.974	0.838	0.514	0.568
Sargan (p-value)			0.480	0.474	0.353	0.365
Difference Sargan (p-value)					0.261	0.307
Long run effects						
Capital	.2216539*** (.0248079)	.06677 (.046377)	-.0254235 (.1028303)	-.0106177 (.1073278)	.11579 (.0937724)	.34613*** (.098613)
Labour	.684217*** (.033439)	.71992*** (.053261)	.9075903*** (.1379076)	.840579*** (.164262)	.784998*** (.126682)	.595008*** (.132263)
r&d	.1077851*** (.017205)	.00848 (.01498)	-.021162 (.0490124)	.018434 (.074051)	.0640049 (.0465346)	.069423 (.058116)
Observations	2379	2379	2379	2379	2379	2379
Number of firms	434	434	434	434	434	434

Note: Heteroskedasticity corrected standard errors in parentheses. All regressions include In DIF2 (DIF3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in levels lagged 2 (3) periods or more (up to 6 periods). In SYS2 (SYS3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in differences lagged 1 (2) period as additional instruments for the levels equations. Difference Sargan is a test of the additional moment conditions used in the system GMM estimators relative to the corresponding first-differenced GMM estimators.

The first point worth noticing is that in terms of R&D the results of different estimations vary. In the OLS estimation, the long-run effect of R&D is positive and statistically significant. This impact, however, becomes statistically insignificant when we control for *permanent* differences across firms implying that the positive productivity impact of R&D is mostly driven by cross-sectional differences across firms. Similar results have also been found in some previous studies (see, e.g., Hall & Mairesse 1995).

The diagnostics in different estimations are satisfactory. We find no evidence of second order serial correlations and the Sargan tests do not reject the validity of instrument sets. To test the validity of different instrument sets, we use Difference Sargan tests. The Difference Sargan tests (columns v and vi) suggest that additional instruments are valid favouring system estimators compared to difference estimators. Hence, we focus on the results of system estimations. The long run effect of capital in the SYS2 estimation seems implausible. The coefficient of capital is very low (0.11). Furthermore, this coefficient is statistically insignificant hence we cannot reject the hypothesis that the coefficient of capital differs from zero which, in turn, is implicitly unconvincing. In the SYS3 estimation, the long run coefficient of capital is 0.35 and statistically significant thus we treat SYS3 as our preferred estimator.

The existing literature indicates that the impact of R&D on productivity potentially varies between industries (see e.g. Harhoff 1998, Bönte 2003). In order to allow these differences, we split the sample into two groups namely higher technology (high-tech) industries and other industries (low-tech). To classify firms as high-tech and other firms, we follow the categorisation by OECD[4]. Since common factor restrictions were rejected in almost all columns (Table 3.1), we focus our further analysis on the long run effects derived from unrestricted versions of the model. The results of these estimations, as well as the corresponding long-run effects, are presented in Table 3.2.

[4] See STAN indicators documentation by OECD.

Table 3.2. "Industry effects"

	High Technology Firms	Other Firms
Value added (t-1)	.4055195***	.5418448***
	(.1059364)	(.0822746)
Capital (t)	.2320377	.3410302**
	(.1488459)	(.1666162)
Capital (t-1)	-.0991546	-.1659099
	(.1197207)	(.1381229)
Employment (t)	.8790607***	.5898657***
	(.1038309)	(.1552936)
Employment (t-1)	-.417552**	-.360287**
	(.1723164)	(.1477867)
R&D (t)	-.0321095	-.0126996
	(.0813966)	(.0274241)
R&D (t-1)	.0428751	.0486073**
	(.0686636)	(.0243259)
m1 (p-value)	<0.001	<0.001
m2 (p-value)	0.936	0.697
Sargan (p-value)	0.163	0.707
long run effects		
Capital	.223528**	.382229***
	(.1061693)	(.1007578)
Labour	.7763228***	.5010938***
	(.1433353)	(.1358012)
r&d	.0181092	.0783747
	(.1064677)	(.0551061)
Observations	878	1499
Number of firms	158	277

Note: SYS3 estimators in all columns. Standard errors in parentheses. See also notes of Table 3.1

The results in Table 3.2 suggest that there are some differences in long run factor elasticities between high tech and other industries. These differences only relate to capital and labour elasticities while the long run elasticity of R&D remains statistically insignificant in both types of industry.

Until now our analyses have focused on a relatively short window of two years to consider the impact of R&D. However, it is possible that the effect of R&D on productivity occurs in the longer run than from *t-1* to *t*. To take into account these longer run effects, we expand the model by adding R&D dated *t-2* to *t-4* to the regression (Table 3.3).

Table 3.3. The model with more lagged R&D variables (Dependent variable=log (value added))

	(i)	(ii)	(iii)
Value added (t-1)	.549997***	.5136943***	.4313889***
	(.0777136)	(.0754618)	(.084063)
Capital (t)	.26857**	.355115**	.1871523
	(.135989)	(.1487572)	(.172245)
Capital (t-1)	-.116213	-.1922668	-.0396958
	(.111693)	(.1192657)	(.149444)
Employment (t)	.79637***	.73543***	.8771483***
	(.116109)	(.12387)	(.109351)
Employment (t-1)	-.52456***	-.44586**	-.5025363***
	(.1294783)	(.134546)	(.1403815)
R&D (t)	-.0225065	-.1922668	-.0537641
	(.0326804)	(.1192657)	(.036786)
R&D (t-1)	.119011***	.115729**	.1490902***
	(.0433662)	(.0485303)	(.055687)
R&D (t-2)	-.061698*	-.0756**	-.0667918
	(.0351043)	(.0358483)	(.0425832)
R&D (t-3)		.0078456	.011955
		(.0128155)	(.0139983)
R&D (t-4)			.0378083***
			(.018963)
m1 (p-value)	<0.001	<0.001	<0.001
m2 (p-value)	0.949	0.661	0.955
Sargan (p-value)	0.520	0.906	0.955
long run effects			
Capital	.338574***	.33487***	.25933***
	(.095263)	(.0929449)	(.0842975)
Labour	.60401***	.59545***	.65882***
	(.1283852)	(.1270959)	(.1218523)
r&d	.0773465	.0727149	.1376996**
	(.0586059)	(.057674)	(.062577)
Observations	2379	1945	1511
Number of firms	434	434	434

Note: SYS3 estimators in all columns. Standard errors in parentheses. See also notes of Table 3.1

When R&D dated *t-2* (column *i* in Table 3.3) and *t-3* (column *ii*) are included in the model, the long run effect of R&D remains statistically insignificant. However, the long run effect of R&D becomes statistically significant when R&D dated *t-4* is included in the model (column *iii*) suggesting that there is a significant lag between

R&D and its positive outcome for productivity. In other words, we do not observe a statistically significant improvement of productivity until four years after R&D.

b. Robustness tests

Next, we perform a number of robustness tests. To save space, we do not report completely the results of these new regressions.

Robustness test 1: In the basic models (Table 3.1), we followed Bond *et al* (2002) and used the logarithm of R&D expenditure directly as an indicator of R&D activity. This method can be motivated as a steady state approximation to the stock (for details, see Bond *et al* 2002). However, our results might be biased, if the steady state approximation is not reliable. To take this into account, we re-ran the model (SYS3) by replacing log(R&D expenditure) with log(R&D-stock). The results of these regressions indicate the following: First, common factor restrictions were rejected at better than 0.001% level. Hence, we calculated the long-run effects using the unrestricted version of the model. Second, the regression echoes our previous result concerning the basic model (Table 3.1, column vi) that the impact of R&D is statistically insignificant (p-value 0.17).

Robustness test 2: Nokia alone accounts for more than 40% of Finland's total private sector R&D thus our results are potentially driven by a single company (Ali-Yrkkö and Hermans 2002). To control this potential bias, we excluded Nokia from the sample and re-ran the basic model (SYS3) and the model with additional lags up to 4 years (column iii in Table 3.3). The results of these new regressions confirm our previous findings. *First*, in a basic model, the long run coefficient of R&D remains statistically insignificant (p-value 0.55). *Second*, this long run effect becomes statistically significant (coefficient 0.12 with p-value 0.07) when lagged R&D variables up to 4 years are included in the regression.

Robustness test 3: Our results may be downward biased, because of double-counting, that is, R&D expenditure consists of R&D labour and investment in physical capital that are already included in the model. Schankerman (1981) argues that in order to estimate R&D elasticity correctly, the production factors capital and labour should be purified by subtracting the R&D share of these factors. Our data enables us to separate R&D labour and non-R&D labour, but we are unable to make the same distinction between R&D capital and non-R&D capital. To take into account the double-counting problem, we make two significant changes. First, instead of the total number of employees we define EMPLOYMENT so that it includes only non-R&D employees. Second, we use the number of R&D employees as an indicator of R&D. We again find that the long-run effect of the basic model is statistically insignificant (p-value=0.45). This long-run coefficient effect becomes statistically significant (p-value 0.005) when R&D lags up to 3 years are included in the regression.

Robustness test 4:

The result that the lag between R&D and productivity improvement lasts even 4 years (Table 3.3) is potentially biased because the sample differs in columns (i)-(iii) in Table 3.3. To eliminate this sample bias, we re-ran models (i) and (ii) by using exactly the same sample (1511 observations) as in column (iii). The results of these new estimations confirm our previous results. Hence, the long-run effects of R&D remain statistically insignificant when R&D dated from *t* to *t-2* and from *t* to *t-3* are included in the model.

c. Another robust check with alternative data

In order to obtain some further evidence on the robustness of our main findings for Finland we perform an additional analysis with an alternative data set. To this end we use the data of Statistics Finland.[5] The data are obtained by linking R&D survey and Financial Statements statistics data. The former is the source of R&D expenditures and the latter the source of labour, tangible capital input, output and industry group information. We use data over the period from 1995 to 2004. The sample is constructed by following the principles similar to those used in our main analysis above.

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[5] These data can be used only at the premises of the Research Laboratory of Statistics Finland following the terms and conditions of confidentiality. To obtain access to these data, please contact the Research Laboratory of the Business Structures Unit, Statistics Finland.

The results for this robustness check are reported in Table 3.4 which basically corresponds to Table 3.3 but is estimated using a different data set. The main difference is that with these data we have also used a five-year lag for R&D in the final model (column iv).

Table 3.4. The results with the data of Statistics Finland

	(i)	(ii)	(iii)	(iv)
Value added (t-1)	.3513337***	.3603309***	.3603329***	.3601987***
	(.0949551)	(.0948593	(.0952338)	(.0986288)
Capital (t)	.0600468	.1201155	.1189037	.3112129
	(.1877684)	(.1921416	(.1912831)	(.2974335)
Capital (t-1)	.1317492	.0605182	.0593915	-.1161565
	(.1969182)	(.2035592	(.2033843)	(.3184455)
Employment (t)	.2032373*	.1466756	.1478092	.097645
	(.1107166)	(.1183811)	(.1189475)	(.163145)
Employment (t-1)	.14579	.1735233*	.1675747	.172999
	(.0964275)	(.1028646)	(.101956)	(.1469104)
R&D (t)	.124691**	.0852948	.0856557	.0465214
	(.0504196)	(.0585696)	(.0586188)	(.0772647)
R&D (t-1)	-.0290135	-.0392594	-.0445688	.0353017
	(.0455392)	(.0476146)	(.047765)	(.0621148)
R&D (t-2)	-.0234893	.0231926	.0272967	-.0153376
	(.0366691)	(.0424994)	(.0417877)	(.0566741)
R&D (t-3)		.0464418**	.0466125**	.0451341*
		(.0216947)	(.0219052)	(.0262765)
R&D (t-4)			.0092727	.0020554
			(.0179138)	(.024273)
R&D (t-5)				.029416
				(.0270364)
m1 (p-value)	<0.001	<0.001	<0.001	<0.001
m2 (p-value)	0.200	0.259	0.271	0.172
Sargan (p-value)	0.103	0.132	0.125	0.030
long run effects				
Capital	.2956776***	.2823862***	.2787311***	.3048703***
	(.0882421)	(.0926058)	(.0938545)	(.0982551)
Labour	.538069****	.5005695***	.4930439***	.4230126***
	(.118974)	(.1231685)	(.1245246)	(.1380925)
r&d	.1112872*	.1808274***	.194271***	.2236491**
	(.0624691)	(.0680827)	(.074024)	(.1026302)
Observations	1496	1496	1496	1496
Number of firms	558	558	558	558

Note: SYS3 estimators in all columns. Standard errors in parentheses.

Generally these estimations confirm our earlier main findings. R&D does have an economically and statistically significant effect. More specifically, we obtain further evidence that R&D investment does not become productive as soon as it is put in place. We find that a window of about 5 years backwards may be needed to capture the full impact. Compared to a short window of two years (i.e. when only current and one-year lagged R&D are included) where the coefficient for the long-run effect is 0.105 (standard error is 0.064), the long-run effect of R&D is about doubled to 0.224 (standard error is 0.103) when R&D is measured over a five- year period.

4 CONCLUSIONS

In this paper, we analysed the impact of R&D on firms' productivity using a large panel data of Finnish firms over a nine-year period from 1996 to 2004. As a robustness test, we also used another database of Finnish firms to confirm our results. We studied the productivity effect of R&D by employing a dynamic production function approach (Bond *et al* 2002).

Our results are two-fold. *First*, in the short run (in 1-2 years) we find no productivity impact of R&D that is statistically significant. This result was echoed when the model was estimated separately in high tech and low tech industries. *Second*, R&D does have an economically and statistically significant impact when we took into account R&D efforts made 3-5 years before. Hence, a window of almost 5 years was needed to capture the full impact of R&D.

For earlier Finnish results with firm data, Rouvinen (2002) has found evidence of lags between 4-5 years in the productivity effect of R&D investments. Further, in an analysis of micro-level sources of industry productivity growth, Maliranta (2005) found that R&D may also increase industry productivity through intra-industry restructuring between plants, indicating the role of creative destruction in innovative efforts. It was found that this mechanism involves lags of several years.

It is crucial to note that our results show the average effect of the R&D. In practice, there are likely to be considerable heterogeneity in the magnitudes of the effect between different firms. From the point of view of policy implications it would be important to distinguish such groups of firms where the effects of R&D inputs are highest or even positive, that is, which firms use R&D efficiently. For instance, Maliranta and Rouvinen (2004) found that the productivity effects of the use of ICT were considerably greater in the firms that have a relatively young establishment than in those firms whose establishments (and organisations) are old. The search of similar complementary factors of the R&D should have a high priority in future research. They might include such factors as intensity of competition in the product markets or human capital in the firm and in the region.

Our results have an important policy implication. The public sector in almost all industrial countries tries to foster technological change by using a variety of instruments, such as R&D loans and subsidies, national R&D laboratories and tax cuts. Our results suggest that there is a considerable lag between investment in R&D and its effects, implying that any type of policy to promote business R&D should have a long-term view lasting at least 5 years. As a consequence, evaluating technology policy requires taking into account these long lags between R&D activity and its impacts.

5 APPENDIX

Data appendix

The data related to financial reports came from Balance Consulting Ltd. and *Talouselämä* magazine's top 500 database.

R&D expenditure

R&D expenditure of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers. The variable was deflated using the GDP price index (2000=100).

Value added

Value added was computed directly from the income statement of the firm. It was calculated by summarising operating profit, personnel costs, depreciation and rent costs. The variable was deflated using the industry level price indices (2000=100).

Knowledge capital stock

Capital stock was calculated based on perpetual inventory calculations using a depreciation rate of 15 %, i.e., $G_t = (1-0.15)G_{t-1} + R_t$, where R_t is R&D expenditure. The variable was deflated using the GDP price index (2000=100).

Capital stock

Capital stock was calculated based on perpetual inventory calculations using a depreciation rate of 15 %, i.e., $K_t = (1-0.08)K_{t-1} + I_t$, where I_t is investment. The capital stock in the initial year was defined to be equal to capital assets in that year. The variable was deflated using the price index of capital goods (2000=100).

Employment

The total number of employees of the firm as reported in the investment survey by the Confederation of Finnish Industry and Employers or in the database of Balance Consulting Ltd.

Net Sales

Net sales came directly from the income statement of the firm. The variable was deflated using the industry level price indices (2000=100).

Table A.1. Basic results with common factor restrictions (Dependent variable=log (value added))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Value added (t-1)	.75349*** .021338	.2215774*** .035279	.3825919*** .0554548	.3303431*** .1238899	.5344932*** .04965	.56434*** .076295
Capital (t)	.1021865*** .033824	.049445 .032754	-.0469065 .128	.0151752 .1321912	.0347964 .1237187	.289844** .134332
Capital (t-1)	-.0475466 .0334627	.0025298 .0352704	.0312099 .0847087	-.0222855 .0994217	.0191046 .0987529	-.13905 .109737
Employment (t)	.66464*** .068508	.67549*** .06828	.8100222*** .1213321	.816071*** .1311999	.7474402*** .115134	.814581*** .106914
Employment (t-1)	-.495973*** .0677018	-.115078* .065794	-.2496686** .1019975	-.253172* .1500899	-.382018*** .114404	-.55536*** .123594
R&D (t)	.0043114 .0088615	0017498 .010564	-.0361816 .0311366	-.0190799 .0421365	-.014715 .0310852	-.021988 .033539
R&D (t-1)	.0222587** .0091218	.00485 .01021	.0231161 .025358	.0314241 .0279242	.0445097* .0255098	.052233** .025863
m1			<0.001	<0.001	<0.001	<0.001
m2			0.974	0.838	0.514	0.568
Sargan (p-value)			0.480	0.474	0.353	0.365
Difference Sargan (p-value)					0.261	0.307
COMFAC- Restrictions (p-value)	2.578e-48	.00255981	.00716041	.13553373	1.244e-11	1.347e-12
Structural parameters						
ρ	.81561973*** .00377035	.17443122*** .02704014	.267258*** .039431	-.01632028 .06795336	.35128987*** .02626229	-.05464147 .04625691
β_K	-.0806258*** .00279386	.01761605** .00904858	-.075046*** .0237973	-.04149372 .04187427	-.19245*** .0150782	.04837172* .02590317
β_N	.6437693*** .0163526	.62088851*** .05021068	.664692*** .0834373	.730344*** .121828	.702159*** .070808	.772028*** .06796162
β_R	.05396509** .02126673	-.00810681 .03179605	-.02584126 .04778252	.03072579 .05186143	.04211857 .04490126	.00110436 .04016965

Note: 434 companies, 2235 observations in all estimations. Standard errors in parentheses. All regressions include In DIF2 (DIF3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in levels lagged 2 (3) periods or more (up to 6 periods). In SYS2 (SYS3) estimates, the set of instruments includes *k*, *n*, *y* and *r&d* in differences lagged 1 (2) period as additional instruments for the levels equations. Difference Sargan is a test of the additional moment conditions used in the system GMM estimators relative to the corresponding first-differenced GMM estimators. COMFAC is a test of common factor restrictions which is distributed under the null as a χ^2 with degrees of freedom equal to the number of restrictions (p-values in round brackets).

Table A.2. Basic results with COMFAC restrictions (Dependent variable=log (Net sales))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Net sales (t-1)	9195657*** .0113995	.3364145*** .0352801	.4140447*** .1165933	.4335505*** .1317551	.650956*** .0771696	.7611612 .0684525
Capital (t)	.119761*** .0369207	0881508*** .0340493	.0840487 .1080238	.0437145 .1147277	.2073351** .1037485	.1720393 .110358
Capital (t-1)	-.09537*** .03624	-.0253882 .0285423	-.1036504 .0671401	0808949 .0773589	-.1066472 .0766824	-.0588316 .0948573
Employment (t)	.62753*** .09103	.6554664*** .0873966	.8593437*** .1208942	.8488268*** .1413431	6554691*** .122789	.8220424*** .130632
Employment (t-1)	-.58401*** .09181	-.190274*** .074324	-.2807184** .1291195	-.3381568** .1741073	-.4415475*** .1387083	-.6988784*** .1361469
R&D (t)	.0073366 .0082229	.0093269 .0090179	-.0393239 .028185	.0043707 .03274	-.0147791 .0289551	-.0614071* .0356102
R&D (t-1)	.0099591 .0082619	.0001267 .0086194	-.009803 .021764	.0179646 .0268354	.0286426 .0243673	0729399** .0294966
m1			<0.001	<0.001	<0.001	<0.001
m2			0.623	0.663	0.824	0.800
Sargan (p-value)			0.158	0.066	0.428	0.127
Difference Sargan (p-value)					0.972	0.718
COMFAC- Restrictions (p-value)	8.765e-88	3.068e-15	.00765326	.0222608	3.951e-11	6.723e-20
Structural parameters						
ρ	1.08136*** .00219883	.22428846*** .02583089	.05972391 .04949945	-.0492615 .07104349	.30681069*** .02416071	.16462915*** .03454623
β_K	-.2976782*** .00163091	-.01336131* 00713444	.00401078 .02258347	-.03007419 .03221638	-.1475056*** .01227519	-.0818902*** .0166526
β_N	.6053441*** .00732443	.629924*** .04637709	.76316258*** .1020203	.76272357*** .13159359	.61848304*** .06201485	.78100708*** .06727285
β_R	.00324189 .01110685	-.01027752 .03320885	.05567103 .05462533	.0853136 .05204942	.1043554** .05090219	-.0035432 .04971575
Observations	2379	2379	2379	2379	2379	2379

Note: See notes of Table A.1

Table A.3. Basic results without COMFAC restrictions (Dependent variable=log (Net sales))

	OLS	Fixed effects	DIF2	DIF3	SYS2	SYS3
Net sales (t-1)	9195657***	.3364145***	.4140447***	.4335505***	.650956***	.7611612
	.0113995	.0352801	.1165933	.1317551	.0771696	.0684525
Capital (t)	.119761***	0881508***	.0840487	.0437145	.2073351**	.1720393
	.0369207	.0340493	.1080238	.1147277	.1037485	.110358
Capital (t-1)	-.09537***	-.0253882	-.1036504	0808949	-.1066472	-.0588316
	.03624	.0285423	.0671401	.0773589	.0766824	.0948573
Employment (t)	.62753***	.6554664***	.8593437***	.8488268***	6554691***	.8220424***
	.09103	.0873966	.1208942	.1413431	.122789	.130632
Employment (t-1)	-.58401***	-.190274***	-.2807184**	-.3381568**	-.4415475***	-.6988784***
	.09181	.074324	.1291195	.1741073	.1387083	.1361469
R&D (t)	.0073366	.0093269	-.0393239	.0043707	-.0147791	-.0614071*
	.0082229	.0090179	.028185	.03274	.0289551	.0356102
R&D (t-1)	.0099591	.0001267	-.009803	.0179646	.0286426	0729399**
	.0082619	.0086194	.021764	.0268354	.0243673	.0294966
m1			<0.001	<0.001	<0.001	<0.001
m2			0.623	0.663	0.824	0.800
Sargan (p-value)			0.158	0.066	0.428	0.127
Difference Sargan (p-value)					0.972	0.718
Long run effects						
Capital	3032141***	.0945811**	-.0334526	-.0656378	.2884676***	.4739919***
	.0604921	.048457	.1061569	.1273751	.1033099	.1405141
Labour	5410231***	.7010293***	.9874905***	.9015279***	6128786***	0.5156788***
	.0811433	.0556399	.1552027	.1847106	.1417011	.2109163
r&d	.2150297***	.0142462	-.0838406**	0394302	.0397186	.0482869
	.0456784	.0140944	.0424006	.0733125	.0476508	.0828358

Note: See notes of Table A.1

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