Regional impacts of R&D and public R&D funding

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1. INTRODUCTION

Recent research on regional economics has also lately focused on R&D. It has been emphasized that R&D is even more concentrated than production. Kelly and Hageman (1999) found that in the USA R&D tends to concentrate in certain locations across industries. Audretsch and Feldman (1996) have pointed out that innovative activity has greater propensity to cluster especially in the industries with a high R&D intensity than in other industries. To what extent the observed clustering of these studies depend on the so-called natural advantages, discussed by Ellison and Glaeser (1997), and to what extent they depend on knowledge spillovers, is unclear. Locations of R&D may also be affected by such physical spillovers as transportation costs (see Krugman, 1991). Finally, besides the above-mentioned factors labour and financial market imperfections can also be responsible for concentration of R&D activity. Public intervention through public funding decisions may also affect the geographical distribution of firms' R&D activities.

In this study we tend to focus on the effects of intellectual spillovers. The study recalls or resembles us of, in that respect, the papers by Adams and Jaffe (1996) and Orlando (1999), who have empirically tested the impacts of explicitly defined external R&D sorted into different pools along geographic and technological dimensions. More specifically, in this study we empirically test the importance of geographic distance in the determination of R&D investments, productivity and employment. But technological proximity is also examined. We use industrial proximity as a rough measure of actual technological proximity which is the proximity between a firm's and other firms' research space.

When geographic or technological distance shortens, the positive spillover effect strengthens, but the plant's own R&D may then be more easily replaced by external R&D. Thus, it is not even clear on the basis of theory whether geographical or technological proximity, associated with other firms' R&D, has a positive or negative influence on a firm's R&D investments. In fact, the purpose of the empirical part of this project is to test empirically ambiguous theoretical implications. On ground of theory the industrial and geographical closeness should affect rather positively productivity. Also this is tested empirically. We consider also the interaction between the firms' R&D activity and total employment. It is not clear how the other firms' R&D affect on employment. The net effect could easily be zero, if some regions specialise in industries which use a lot of R&D and the other regions in activities which require hardly any R&D. How R&D affect total employment in investigated empirically in this study. The empirical analysis focuses also on the role of public R&D funding. The effects of the staff's education are also evaluated.

One of the main contributions of this study is the constructing of a large R&D database which includes the approximates of R&D stocks for practically all the relevant firms in Finland who have been active in R&D during the years 1985-1998. In this data set the firms' R&D is allocated to be located in certain municipalities. This also makes it possible to link R&D data to the firms' plants in the same locations. This large data set of R&D stocks is constructed by using partly imputed values for R&D investments. But in the approximation of missing values we have utilized observations of R&D investments in other years, the rate of growth of the specific industry's R&D and the business register which gives information about the plants' and firms' existence in various years.

R&D data set is also sorted at the three-digit NACE level. The countrywide data on R&D stocks makes it possible to specify external R&D stocks for every firm in a certain location in a consistent way. The external R&D also includes the same firm's R&D in different locations as well as the other firms' R&D. The external R&D is then divided according to its geographical and industrial dimensions.

This study relies on the data of R&D stocks which does not exclude any relevant segment of the considered countrywide market. Foreign spillovers, though, are not taken into account. Because of good covering, the specified pools of external R&D

stocks, corresponding to observations, are consistent with each other. This confirms the reliability of the estimated elasticities for external R&D.

This project also includes a short theoretical note on the determination of R&D investments (in Appendix C) and a separate paper on cooperation in R&D. In Appendix C we focus on R&D investments and show that because the other firms R&D can be substituted for the firm's own R&D, the total effect from external R&D need not be positive.

In the paper which considers cooperation in R&D we stress that external influence from other firms' R&D can also be based on voluntary cooperation, besides involuntary spillovers. In this paper we focus on cooperative agreements and point out that free-riding can lead to a situation where closer cooperation decreases firms' R&D. However, if the possibilities to monitor each other's behaviour improves, cooperation may even increase R&D in so far as the firms are risk-averters. It is possible that the monitoring possibilities are better, if the firms are near each other. This gives us a new reason to believe that closeness reinforces R&D activity. The task of empirical analysis is to test this implication too.

2. DATA

Data sources of this study are:

- Business Register (plant and firm level data)
- R&D surveys
- Innovations surveys
- Employee education and work experience data
- Industrial statistics data

All the basic data are produced by Statistics Finland. Data on firms' internal R&D investments are obtained from R&D surveys from the years 1985, 1987, 1989, 1991, 1993, 1995, 1997 and 1998. Data on the sources of firms' R&D funding cover the years 1991, 1993, 1995, 1997 and 1998. Additional data on the R&D investments in 1996 have been obtained from the innovation survey 1996.

The basic data do not give exact information of a plant's R&D investments. Since 1995 there has been, however, information of the geographical location of each firm's R&D investments. More specifically, R&D is divided into various municipalities. R&D surveys from earlier years specified in which county (province) each firm's R&D was located. Using this rather coarse regional distribution and, on the other hand, the location of each firm's plants (from the Business Register), we have approximated the locations of each firm's R&D by municipalities.

Using the knowledge about a firm's internal R&D by municipalities we have constructed data set on firms' R&D stock at each location. The R&D survey does not cover all the firms in all the years. In the years 1985, 1987, 1989 and 1995 data were more extensive than in the years 1991, 1993, 1997 and 1998.[1] R&D stocks

[1] A more detailed description of data characteristics is given in Husso, Leppälahti and Niininen, 1996.

have been calculated for every such a location of a firm that has appeared at least once in R&D surveys during the years 1985-1998.

We have constructed this data set by approximating missing observations on R&D investments by means of observations in other years. For example, if a firm's R&D investments in a certain municipality are observed in the years 1991 and 1995, but not in the year 1993, the missing 1993 observation is approximated using figures from the years 1991 and 1995. But if there are observations, for example, only from the years 1995 and 1993, and if the Business Register does not confirm that a firm has been active in the municipality in question in other years, R&D investments and calculated R&D stock as well for the other years is set at zero level. On the other hand, if an observation only from 1995 is available, but the Business Register confirms that a firm has been active in the same municipality in the years 1991 and 1993 too, missing observations are approximated using the year 1995 observation and the average R&D growth rate in the same industry (using 1-digit NACE classes). In this calculation we have explicitly taken into account the effects of the changes in sample sizes during the observed time period. It must be noticed that defined industrial classification makes it possible to specify industrial proximity between the firms which is still quite a coarse estimate of real technological proximity.

The Business Register is also used to complete data concerning a firm's three-digit NACE level.

Throughout the study we have assumed that all the plants of each firm have a common industry NACE level. This simplifying assumption is made because R&D surveys do not give any information of the NACE level associated with R&D in various locations. Besides, the firm’s announcements of their

NACE level and especially of the plants’ NACE level seem to be quite time inconsistent, and so the simplification done in this study has its own merits. Besides, the plant, which has a different NACE code than a parent firm, often directly supports the parent firm in its R&D. This also defends our procedure to specify only one NACE code for the whole firm. From the data set used in the productivity analysis we have, however, omitted such observations of which the NACE level is in contrast with the information given by industrial statistics.

R&D stocks have been constructed following two alternative approaches. In the plant-level approach the firm's local R&Ds are regarded as independent of each other. So, if the firm shuts down its plant in one municipality, the accumulated R&D stock does not move to any other location, whereas, in the firm-level approach we assume that no R&D is lost, even if the firm's presence in one location ceases.

Both in plant-level and firm-level data the merges in the years 1996 and 1997 have been taken explicitly into account.

Plant-level approach

Observed and interpolated R&D investments and information concerning firms' activity in various locations at different dates are then used to construct R&D stocks. Let R_{ijt} connote firms i's R&D stock in municipality j in period t. Then R_{ijt} has the representation

(1) $$\mathrm{R}_{\mathrm{ijt}} = R_{ijt-1}(1 - \delta) + \mathrm{RD}_{\mathrm{ijt}},$$

where RD_{ijt} denotes the real value of firm i's R&D investments in site j in period t. R&D investments are deflated by the private sector's earnings index. The depreciation rate δ is assumed to be 0.15. In addition, it has been assumed that the annual growth rate of R&D investments was 10 percent before 1985, so that year's 1985 R&D stock has been obtained by multiplying the same year's R&D investments by $1/(1-(\delta/1.1))$. Unfortunately, the Business Register does not offer any information about firms' activity before 1985, so that a more sophisticated method to evaluate the starting values for R&D stock is not available.

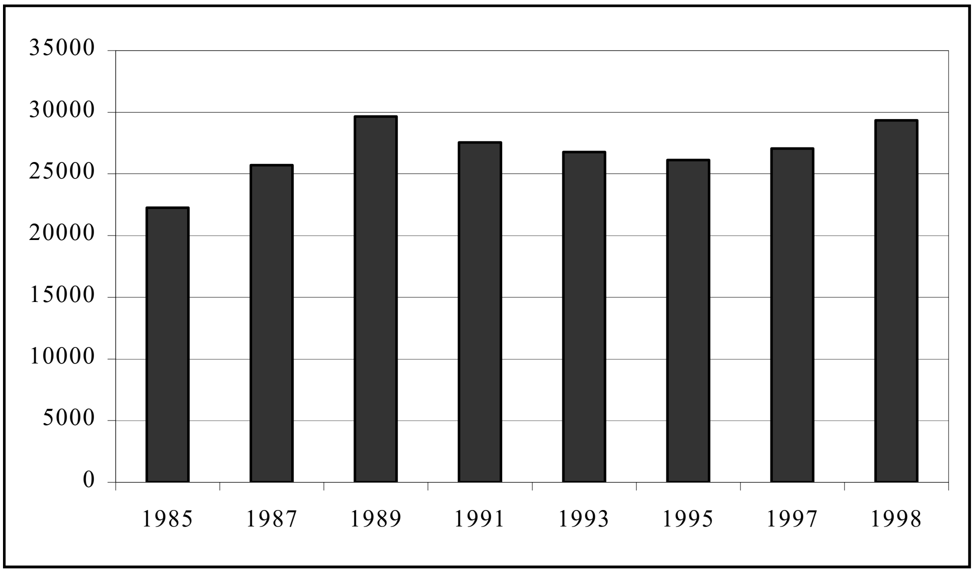
The number of observed plant-level R&D stocks is around 5590 before 1997 (see table 2.1). Due to the merges this number decreased to 5533 in 1997 and 1998. The frequency of the announced non-zero R&D investments varies from 893 to 2063. The construction of a balanced panel with non-zero R&D's would have dropped the number of annual observations remarkably. The R&D stocks and the pools for external R&D based on this panel would not have been representative enough.

Table 2.1. The number of observations in the panel - the analysis of R&D intensity

	1987	*1989*	*1991*	*1993*	*1995*	*1997*	*1998*
R&D stocks	5590	5590	5590	5590	5590	5533	5533
Announced R&D investments (zero and nonzero)	2060	1875	2712	2816	4217	4360	3349
Announced R&D investments (nonzero)	1104	1192	1064	893	1865	1829	2063
New firms (whose R&D stock is zero in previous periods)	417	234	568	479	733	466	408

Figure 1 shows that heavy investments in the late eighties raised the total R&D stock quite rapidly. During the deep recession in years 1991–1994 the real value of R&D investments dropped and with it the R&D stock too. The used deflator is also responsible for the time profile of R&D stocks. The earnings level in the private sector rose quite rapidly in the late eighties. With the recovery of R&D investments R&D stock has started to grow again toward the end of the last decade.

Figure 1. The total R&D stock in Finland (mmk-85p)



Each R&D stock observation has been defined as belonging to a certain firm, in a certain branch of industry (following three-digit NACE-classes) in a certain municipality. This makes it possible to sort external R&D stocks into geographically near and distant pools, as well industrially near and distant pools. Basically, the data approximates all the R&D in Finland. Geographically near R&D is defined as that conducted within the same sub-regional unit. The whole country consists of 88 sub-regional units. The total number of municipalities was 452 (at the beginning of 1997). External R&D is defined to be industrially near, if it belongs to a firm's own industry group according to three-digit NACE.

In the basic R&D data of this study there are firms from 180 (three-digit NACE level) industry branches.

In this study we analyse the determination of R&D investments, productivity and employment. R&D investments, productivity and employment are explained by past R&D stock variables. In the analysis concerning R&D investments, only the announced (not imputed) R&D investments are used as explanatory variables. In this analysis the constructed data set for R&D stocks also makes it possible to form consistent external R&D stock variables for each R&D investment observation.

R&D stock variables of this study are:

- the plant's own R&D stock in certain municipality
- the firm's own R&D stock in another municipality in the same sub-region
- the firm's own R&D stock in another sub-region
- other firms' R&D stock in the same industry within the same sub-region
- other firms' R&D stock in the same industry within another sub-region
- other firms' R&D stock in another industry within the same sub-region
- other firms' R&D stock in another industry within another sub-region.

When only geographical division is taken into account, the other firms' R&D stocks consist of

- other firms' R&D stock in the same sub-region
- other firms' R&D stock within another sub-region.

Firm-level approach

In the firm-level approach R&D stock is obtained from

(2) $$\mathrm{R}_{\mathrm{it}} = R_{it-1}(1 - \delta) + \mathrm{RD}_{\mathrm{it}},$$

where RD_{it} denotes the real value of firm i's R&D investments in period t.

In the firm level approach, a firm's R&D stock is assumed to be divided between various municipalities in the same proportion as in the plan-level approach in each period. This assumption makes it possible to sort external R&D stock by geographical and industrial proximity as in the plant-level approach. In the firm-level approach each firm's own area is determined by the presence of its plants in various municipalities.

Productivity

In the analysis of productivity in Finnish manufacturing we use the same R&D stock variables as in the analysis concerning the determination of R&D investments. In this analysis we explain the productivity of all those plants which belong to such a firm which conducts R&D. Then only those firms which have responded to R&D surveys are taken into account.

Table 2.2. The number of observations in the panel - the analysis of productivity

	1987	*1989*	*1991*	*1993*	*1995*	*1997*	*1998*
Total number of observations	1670	1362	1951	1946	2171	1731	1378
The number of those sites where R&D stock (with 2 years lag was positive	616	573	693	679	808	783	730

Employment

The impact of R&D on total employment is analysed with two separate data sets. The first data set is almost the same as the data used in productivity analysis. Thus, this data set includes all the plants of such manufacturing firms, which have responded on R&D surveys, also those plants which are not active in R&D. The observations about the size of a plant's staff are then also obtained from Industrial statistics data.

The other data set is the same as the large data set used in the analysis of R&D investments. This data set includes all the industries, but of R&D active firms only those plants of which have invested in R&D. This data set includes also those firms of which R&D investments are zero. In these cases only the principal place of business is taken into account. The observations about the size of personnel, which include in this data set, are obtained either from Business Register (plant and firm level data) or from R&D surveys. For the years 1985-1993 a plant-level variable of the staff size is obtained directly from Business Register. This concerns also the observations from the one-plant firms in the years 1995-1998. In the years 1995-1998 the multi-plant firms' the staff size, both current and lagged with two years, is obtained by multiplying the firm-level staff size by a plant's share of current R&D investments. Because those plants which have no R&D are not taken into account, this procedure partly overestimates the plant-level staff size of multi-plant firms in the years 1995-1998.

Zero values and logarithms

Because explanatory R&D variables have zero values also, we have taken logs of all R&D variables using transformation log(x+1). Then log(x+1) = 0 when x = 0. To control the effects of this transformation we have specified a dummy for those variables which have zeros' in the original data. It turned out that the sign of the dummy variable concerned tends to be opposite to the sign of the coefficient for the transformed variable. The estimates of these dummies are not reported.

The basic data also include a variable which describes public R&D funding and the education levels of the whole staff and R&D staff.

3. R&D INVESTMENTS

3.1. On the theory of R&D investments

R&D spillovers can be divided into physical spillovers (as in Krugman,1991) and into knowledge spillovers (discussed in Glaeser et al., 1992). In R&D knowledge spillovers are more important. If external R&D is useful for a firm, and if knowledge included in external R&D stock is available for a firm even without voluntary co-operation, then external R&D has a spillover effect on a firm's behaviour. As a spillover external R&D can either increase or decrease a firm's R&D investments. According to the basic hypothesis the external R&D is a complement for a firm's own R&D. Then external R&D increases a firm's own R&D investments. Being a substitute for a firm's own R&D, external R&D may, however, decrease a firm's R&D investments.

Competition effect

External R&D also affects a firm's R&D investments through a market situation. By process innovations (see Cohen and Klepper, 1996) firms can improve both productivity and profitability. But product innovations can be viewed as creating a new product variant with improved quality which, in the form of transient monopoly power, gives a firm an opportunity to temporarily enlarge a price-cost margin. As soon as the competitors manage to imitate the innovator this advantage is eliminated. In the analysis of the theoretical part it is stated that through a competition effect external R&D can easily decrease a firm's own R&D. But this result is not inevitable (see Appendix C).

Cooperation in R&D

Closer cooperation on R&D does not necessarily contribute to the increase in R&D investments either. For example, Cohen and Levinthal (1989) specify a model in which separate R&D investments (or R&D capital) are substitutes. Abstracted from R&D's capability to affect absorptive capacity, cooperation will, in their model, lead to decreases in the level of R&D spending. This effect arises because the joint effort creates costs savings when duplicating activities are omitted. In their results from empirical research Irwin and Kenow (1996) conclude that even joint effort in the form of a joint R&D consortium on the net rather decreases the level of R&D spending. This result refers again to the fact that an opportunity to reduce duplication of a partner's R&D spending dominates the possible opposite effects. How other firms' R&D affect a firm's own R&D is analysed more closely in Appendix C.

All in all, voluntary cooperation intensifies the effect of external R&D on a firm's own R&D. Cooperation improves a firm's opportunities to take advantage of a partner's innovation. More intense cooperation, however, strengthens the R&D spillovers away from the firm. The final effect of cooperation on a firm's R&D investments depend on the nature of cooperators' R&D assets. These assets can be either substitutes or complements. As Katz (1986) has noticed, the cooperation may also have an impact on the industry level competitiveness. This affects the incentives to cooperate. For example, if the process innovation lowers the industry standards for marginal costs, the incentives for R&D cooperation diminish. The presence of potential partners as such may already lead to local spillovers and thus at least into implicit cooperation. Cooperation in R&D activity promotes the diffusion of new knowledge.

As Cohen and Levinthal (1989) have noticed, R&D as such develops and maintains the firms' capabilities to assimilate and exploit externally available information. The staff's qualifications have an influence in the same direction, which creates an additional motivation to increase or maintain R&D. This diffusion effect can be strengthened by founding various types of joint R&D ventures or R&D centres (see Branstetter and Sakakibara 1998). But one must also notice that, due to spillovers, close cooperation may, however, weaken the incentives for socially efficient R&D production. Whether R&D can centres alleviate this moral hazard problem and also lead firms to internalize the externalities of spillovers and in this way strengthen the firms' incentives to make R&D investments is still an open question. From the viewpoint of a single firm there seems to be a trade-off between cooperation and being isolated. In close cooperation with other firms in an industry innovations are imitated at a faster pace. On the other hand, in isolation a firm cannot learn from others.

In a separate theoretical paper of this study we consider a case in which risk averse firms agree in advance to share R&D results but not R&D costs. The model considered abstracts from those implications which arise when R&D assets are either substitutes or complements. We, however, focus on a free rider problem, instead. Real R&D expenditure is assumed to be unobservable, which creates a moral hazard problem. The firms make a contract at the first stage about the intensity of cooperation and at the second stage about the research effort. Moral hazard weakens the firms' motives to invest in R&D when a firm is in close cooperation with another firm. But diversifying the portfolio of R&D projects through cooperation increases firms' utility. It turns out that in the absence of monitoring firms choose either high effort and low intensity of cooperation or alternatively low effort and maximal intensity of cooperation. If a firm can monitor a partner's real R&D effort through a signal, moral hazard problem - which decreases the incentives to invest in R&D - can weaken to the extent that risk averse and independent firms choose high effort and maximal intensity of cooperation, even if they were indifferent between high effort and low effort in isolation.

Technological and geographical proximity in R&D activity

In the literature there are studies which consider concentration in innovative activities. Audretsch and Feldman (1996) show that in American industries with high R&D intensity innovative activities have a greater propensity to cluster than in industries where knowledge does not play so great a role. According to Kelly and Hageman (1999) the location of a sector's R&D activity in the USA is determined more by the location of the other sector's innovation than by the location of its own production. This means that all sectors tend to locate their R&D in the same regions. In the long run, the social consequences of this newly formed economic landscape are remarkable.

Whether geographical or technological distance affects the strength of the R&D spillover effect depends on various issues. It is natural that technological proximity to a certain extent is required, if external R&D is utilized. Modern information technology may reduce the importance of geographical nearness. But still, a short geographical distance may facilitate the birth of personal and informal contacts which are often necessary for more intense interaction and co-operation.

When R&D assets are substitutes for each other, external R&D has a negative impact on a firm's R&D investments. The productivity effect is then also positive. On the whole, all kinds of spillover, however, alleviate the firm's economic position. But can external R&D harm a firm or be a signal of such a factor which damages the firm in question? These kinds of genuinely negative impacts may arise through an imperfectly behaving R&D factor market. By this we refer to the labour market or the financial market. Also a battle for a limited public R&D funding may arise negative impacts from external R&D on a firm's R&D investments.

Also, these negative impacts through a poorly operating factor market can depend on either geographical or technological proximity. For example, a fast enlargement of R&D activity in one location can weaken firms' opportunities to get finance or qualified labour for their R&D projects in other locations.

3.2. The empirical model

Like the concentration of productivity the concentration of R&D activity is also affected either by so-called natural advantages or by spillovers (see Ellison and Glaeser, 1997). Kelly and Hageman (1999) find that innovations cluster strongly, independently of the distribution of employment, with all sectors tending to locate their R&D in the same regions. According to them, the agglomerative forces considered by Ellison and Glaeser (1997) that cause different sectors to concentrate production in different regions are different from those that affect innovation.

We also compare the concentration of R&D with that of production in this study. The main emphasis is, however, on the analysis concerning the impacts of external R&D. The empirical model is constructed in the way which makes it possible to test The spillover effect separately.

The model

Let RD_t denote a firm's R&D investments. Firms are assumed to adjust their R&D to the optimal level in each period. We assume that RD_t is determined according to past R&D stock R_{t-2}, current turnover S_t and external spillovers which are a function of external R&D stock RE_{t-2}. We can write

(3) $$RD_t = f(S_t, R_{t-2}, RE_{t-2})\,.$$

In formula (3) R_{t-2} is determined from R_{t-4}, S_{t-2} and RE_{t-4}. Continuing this recursion we assume that the first observed value for firm's the R&D stock RC_0 is a function of S_0, RE_{-2} and time invariant exogenous factors Z_0, which represents natural advantage. Modelling in this way R_{t-2} in formula (3) comprises all those effects which arise from natural advantages or disadvantages. For example, if a firm is located in a region and in the industry which favour R&D, the effect of this is already shown in R_{t-2}. Turnover S_t, however, describes the firm's own resources to finance R&D in period t.

In model (3) R&D is deflated with the private sector's earnings index. This index reflects the unit costs of R&D. S_t is also deflated with the same index. S_t is thus expressed in terms of real R&D.

Formula (3) for plant i's R&D investments is estimated in the form

$$(4) \qquad RD_{i,t} = cS_{i,t}{}^{\alpha_1} R_{i,t-2}{}^{\alpha_2} \prod_j^k RE_{i,j,t-2}{}^{\beta_j} \prod_j^k N_{i,j,t-2}{}^{\gamma_j} e^{\varepsilon_{i,t}}.$$

The external R&D stock ($RE_{i,t-2}$) above is divided according to geographical and technological proximity into k pools. Variable $N_{i,j,t-2}$ in (4) represents the number of those units which have positive R&D stock in the j'th pool. If the number is large, the spillover effect may be diluted (see Adams and Jaffe, 1994). In (4) $\varepsilon_{i,t}$ is an error term. Taking logs, formula (4) transforms into

$$(5) \qquad rd_{i,t} = c + \alpha_1 s_{i,t} + \alpha_2 r_{i,t-2} + \beta_j \sum_j^k re_{i,j,t-2} + \gamma_i \sum_j^k n_{i,j,t-2} + \varepsilon_{i,t}.$$

Small letters describe logs of the original variables. Because most of the R&D variables of the model can be either positive or zero, the logs are taken in the form: log(x+1). Thus, if x was originally zero, its log-transformation log(x+1) is also zero. Because of this transformation, we add the dummy variable dx for all those variables which can also be zero. Dummy dx=1, if x > 0, and dx=0, if x=0.

Concentration

Following Ellison and Glaeser[2] (1997) and Kelly and Hageman we have constructed a measure for a geographical clustering in R&D by setting $G=\Sigma_i(s_i - x_i)^2$, where s_i denotes sub-region i's share of R&D capital in a sector and x_i is sub-region i's share of production in the same sector. If the distributions of R&D and production are equal, G is zero or close to zero. According to the rule of thumb (employed by Ellison and Glaeser, 1997), concentration is high, if $G > 0.02$, whereas it is low, if $G < 0.02$. The G-value for clustering in 1997 is reported in table 3.1. We have also calculated the sample variance $(1/n)\Sigma_i(s_i - x_i)^2$ which is close to G-statistics, and besides this, the standard deviation of this variance also.[3] If the sample variance is high in proportion to its standard deviation, the variance deviates from zero which shows that regional distributions of production and R&D tend to deviate from each other.

Table 3.1. Clustering of R&D in manufacturing

	G-value	*Sample variance*	*Stdv of sample variance*
Food and tobacco	0,127	0,00144	0,00126
Textiles and clothes	0,058	0,00068	0,00035
Leather	0,191	0,00360	0,00169
Wood	0,036	0,00041	0,00015
Paper and pulp	0,026	0,00045	0,00013
Printing	0,102	0,00119	0,00111
Petroleum	0,166	0,01386	0,00785
Chemicals	0,125	0,00196	0,00144
Rubber and plastic	0,083	0,00105	0,00070
Mineral	0,029	0,00034	0,00017

[2] They compared distribution of production with distribution of employment.

[3] In the formula of sample variance n represents the number of those observations in which either s_i or x_i is non-zero.

Basic and fabricated metal	0,050	0,00057	0,00022
Machinery and equipment	0,056	0,00064	0,00031
Electronic industries and instruments	0,091	0,00111	0,00055
Transport equipment	0,073	0,00091	0,00061
Other manufacturing	0,038	0,00044	0,00020

According to G-statistics the distribution of R&D deviates from the distribution of production particularly in the manufacturing of chemicals and chemical products, food and tobacco, leather products and electrical and optical equipment. Taking also into account the standard deviation of the sample variance, one can say that mainly in the traditional forest industry and in the large metallic industry, electronics included, the regional distribution of R&D deviates from the respective distribution in production. All in all, the calculations show that in the most important branches of manufacturing R&D exhibits strong spatial clustering independently of the distribution of production. In figure 2 sample G-value (n times the sample variance) is compared with the R&D-intensity which is obtained when current R&D stock is divided by turnover.

Figure 2. Concentration and intensity of R&D

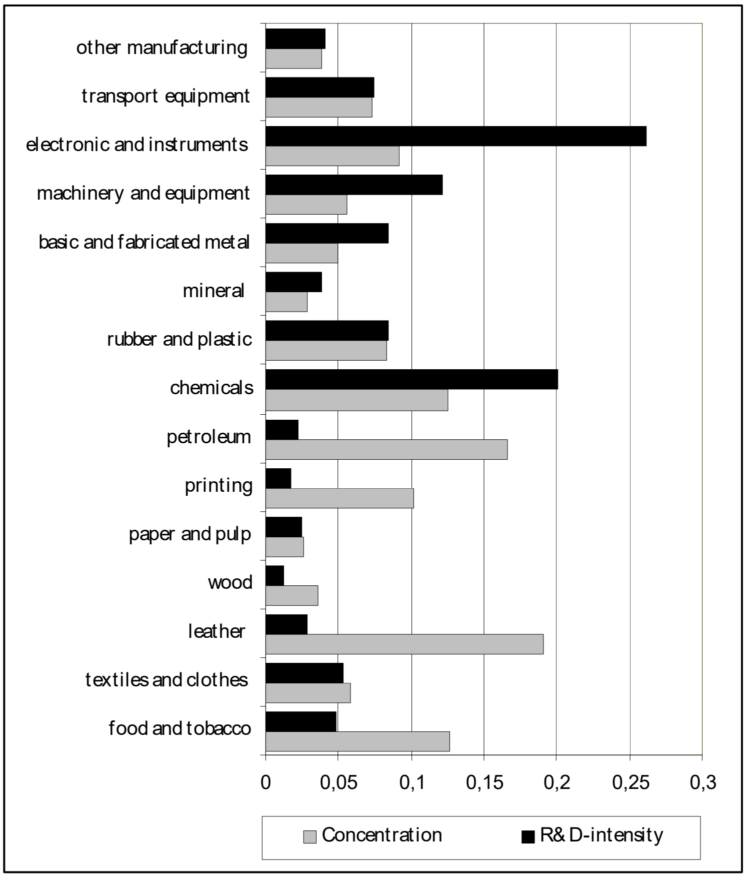


Figure 2 gives only weak support for the previous results of Audretch and Feldman (1996), according to which R&D activity has a greater propensity to cluster in the industries with high R&D intensity. In fact, the correlation coefficient between G-value and R&D intensity reported in figure 2 is only 0.07. In Finland high R&D intensity in the manufacturing of electronic and telecommunication equipment is combined with strong clustering of R&D. But the coexistence of strong clustering and low R&D intensity is also possible, as in the leather and petroleum industries. In the forest industry also R&D activity seems to be concentrated in other sites than production, although the R&D intensity is relatively low.

For the total aggregate of private industries (services included) G-value was 0.029, giving weak evidence of strong clustering in R&D. Observed clustering of R&D is partly explained by the natural advantages of R&D in certain locations.

3.3. Estimation results - R&D investments

Data with non-zero current R&D investments

The estimation results reported in table 3.2 are based on plant-level data. Models of columns (1), (2), (4) and (5) use data the from years 1987-1998. This data set, called data set A (see descriptions in appendix B), does not include those observations whose current R&D investments are zero. Column (3) uses data set A from which also all new R&D plants are excluded. In the estimated models of table 3.2 all the explanatory R&D variables are R&D stocks. By external R&D is meant generally the R&D of other firms. If a plant's own firm is in question, it is mentioned separately.

According to the results, both a plant's own R&D stock in the past and a plant's current turnover have a strong positive impact on the plant’s current R&D investments. The main interest of this study relates to the estimates of external R&D stock. It seems that both geographical and industrial proximity matter. The estimated coefficients for the elasticities of past external R&D stocks in one's own area and its own industry are positive. The same applies to external R&D both in other areas and one's own industry, and in one's own area and other industries. Only a coefficient for external R&D in other areas and other industries does not deviate from zero. Thus, R&D which is remote in both a geographical and technological sense does not seem to have an impact on current R&D investments. Finally, R&D stocks in the other plants of the same firm also have a positive impact.

Table 3.2.

Dependent variable, R&D-investments - Plant-level regression, data set A Period 1987-1998
OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Intercept	3.106* (2.4)	3.418** (2.4)	4.535** (3.5)	2.926* (2.4)	3.010* (2.21)
Turnover, t	0.224** (38.1)	0.226** (38.2)	0.154** (23.3)	0.218** (36.8)	0.224** (37.4)
Own R&D, t-2	0.574** (70.5)	0.574** (70.5)	0.619** (78.5)	0.583** (71.3)	0.562** (68.8)
External R&D, own area, Own industry, t-2	0.047** (6.2)	0.048** (6.3)	0.031** (4.1)		0.051** (5.3)
Number of other units, Own area , own industry, t-2					-0.012 (0.5)
External R&D, own area, t-2				0.084** (10.2)	
External R&D, other areas, Own industry, t-2	0.054** (7.2)	0.053** (7.1)	0.042** (5.5)		0.085** (7.7)
Number of other units, Other areas, own industry, t-2					-0.066** (3.3)
External R&D, own area, Other industries, t-2	0.052** (5.8)	0.038** (3.5)	0.046** (5.4)		0.044** (2.6)
Number of other units, own area, Other industries, t-2					0.013 (0.5)
External R&D, other areas, t-2				0.111 (1.6)	
External R&D, other areas, Other industries, t-2	0.096 (1.3)	0.077 (1.0)	-0.008 (0.1)		0.063 (0.7)
Number of other units, other areas, Other industries, t-2					0.088 (1.1)
External R&D, own firm, Other areas, t-2	0.094** (9.8)	0.092** (9.7)	0.089** (9.2)	0.099** (10.3)	0.176** (14.3)
Number of other units, own firm, Other areas, t-2					-0.529** (11.1)
External R&D, own firm, Own area , t-2	0.143** (6.5)	0.142** (6.5)	0.121** (5.4)	0.139** (6.3)	0.126** (5.7)
Number of other units, own firm, Own area, t-2					0.008 (0.0)
Research in Universities, t-2		-0.009 (0.6)			
R^2	0.593	0.594	0.655	0.587	0.600
MSE	1.350	1.348	1.136	1.371	1.330
N	10009	10009	8213	10010	10009

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

When one evaluates the importance of each R&D pool, the actual size of these pools should also be taken into account. The elasticities for the other firms' R&D stock which is near in both sense is about the same size as the respective elasticity for the pool which is located in other areas but in the same industry. The latter pool is, however, on the average, about nine times larger than the first mentioned pool. Thus, if the other firms' past R&D stock in the same area and industry increases by 100 percent, which is 14186 fixed-price units, a plant's current R&D investments tend to increase by 4,7 percent. However, these same 14186 additional units yield only 11 percent rise in the other firms' past R&D stock in the same industry and in other areas. As a result of this, the model predicts that the current R&D investments would only increase by 0,6 percent.

Comparison between the estimates of the models in column (1) and (3) shows that the basic results do not change although new plants are omitted from the data. Academic research (in technology and data and information processing) in the same sub-region does not seem to have any impact on current R&D investments.

Inclusion of the number of those units whose past R&D stock is positive in the data set brings new light to our understanding of the considered phenomenon. It looks as if the external R&D of other firms in its own industry and other areas loses its power when the number of plants in this pool increases. This explains that it is difficult for a single firm to gather information from a great number of small sources. Thus, a big firm benefits the neighbourhood more than a number of smaller firms whose total R&D adds up to the big firm's R&D. It is remarkable that this same effect also concerns the use of R&D knowledge inside a firm. The usefulness of remote R&D become weaker when the number of senders increases, given the size of remote R&D. Adams and Jaffe already found this ”dilution” effect in 1996. They stressed, however, that this problem is associated with rather the number of recipients rather than the number of senders.

Simultaneous equation model

Owing to the fact that current turnover can be regarded as endogenous, we also estimated R&D investments simultaneously with current turnover in the 2SLS method. In this model, turnover was also explained by real GDP and the past size of the plant's staff. The estimation results are reported in table A1 in Appendix A. Because these results do not deviate in any important respect from the results shown in Table 3.2, more detailed comments are unnecessary.

Large data with zeros for current R&D investments also

In Table A2 (in Appendix A) we report the estimation results from the data set (data set B, see the description in Appendix B) which includes a cluster of zero observations for current R&D investments as well. For those firms whose R&D is zero this data set includes, however, only one location, the site of the firm's principal place of business. For those firms who have nonzero R&D investments this data includes only those plants which also have nonzero R&D. The asymmetry in the data may affect the coefficient estimates.

It should be noticed that zero observations include those cases in which a firm is just indifferent about investing in R&D or not investing. Besides, it includes those cases in which a plant is far from being willing to invest in R&D. R&D investments in the data set can therefore be considered as a censored variable. The zeros of this variable correspond to cases where the profitability of R&D investments is below the threshold value. The Tobit model defines a normally distributed latent variable which gives a distribution for a censored variable as a mixture of continuous and discrete parts. The continuous part applies to positive observations, and discrete part to zero observations.

The estimation results for the Tobit model where the censoring limit is zero deviate in some respects from the results of table 3.2. The plant's external R&D now seem to be a substitute for the plant's own R&D. The sign for the relevant elasticity is negative. Also the effect from other firms' R&D in the plant's own area but on other industries is now negative. The elasticity for the other firms' R&D which is in the same industry but in another area is still positive. Again, the effect from external

R&D which is remote both geographically and technologically is zero. The effect of other firms' R&D which is near in both senses has still positive elasticity. All in all, these results, as far as spillovers from other firms are concerned, do not, however, deviate radically from the previous results presented in Table 3.2. The conclusion according to which geographic distance weakens positive spillover is confirmed by the estimates presented in column 2 of table A2. In the model of column 2, the other firms' R&D is sorted into two pools only. The spillover from external R&D in the same sub-region has a positive impact, and from other sub-regions this impact is zero.

Fixed industry and sub-region effects models

The plant-level fixed effects models take into account only the variation within the considered time period for a plant. The group-level fixed effects model takes also into account a variation indiside a specified group. The estimated fixed effects model for plant i's R&D investment is of the type

$$RD_{i,t} = \alpha_j + \beta A_i + \varepsilon_{i,t} ,$$

where j defines a group, a set A_i is the matrix of explanatory variables and $\varepsilon_{i,t}$ is an error term. In the random effects model group specific α_j is substituted for common α, and $\varepsilon_{i,t}$ has a representation

$$\varepsilon_{i,t} = \mu_j + \nu_{i,t} ,$$

where μ_j is a group specific time invariant factor and $\nu_{i,t}$ is an error term. In the fixed plant effects or random plant effects models j = i.

In Table 3.3 we have reported the estimated coefficients for the models which include either industry or sub-region dummies or dummies for the both of these. Before one goes to the results it should, however, be noticed that there are not very strong reasons to believe that the firms in different industries or regions behave differently from each other, if the plant's own past R&D stock - which already includes the effect of industry and region specific factors - is controlled. But the specified fixed effects models may, however, eliminate such correlation which can produce bias to the estimated coefficients.

Table 3.3.

Period 1987-1998
Dependent variable, R&D-investments - Plant-level regression, data A
Fixed effects models, GLS

coefficient estimate (t-statistics in parentheses)

	180 industry dummies	***180 industry dummies***	***86 sub-region dummies***	***86 sub-region and 180 industry dummies***	***86 sub-region and 180 industry dummies***
Intercept	-0.450 (0.3)	1.102 (0.8)	15.486 (5.8)	6.384* (2.3)	8.091** (2.9)
Turnover, t	0.286** (42.8)	0.288** (43.1)	0.226** (38.0)	0.285** (42.3)	0.286** (42.6)
Own R&D, t-2	0.509** (61.7)	0.514** (62.8)	0.570** (69.4)	0.508** (61.0)	0.513** (62.1)
External R&D, own area, Own industry, t-2	0.006 (0.8)		0.049** (6.4)	0.007 (0.8)	
External R&D, own areas, t-2		0.050** (6.1)			0.017 (0.8)
External R&D, other areas, Own industry, t-2	-0.067** (3.4)		0.041** (5.2)	-0.078** (3.9)	
External R&D, own area, Other industries, t-2	0.038** (4.2)		-0.023 (1.0)	0.000 (0.0)	
External R&D, other areas, t-2		0.0080 (1.2)			-0.306* (2.0)
External R&D, other areas, Other industries, t-2	0.164* (2.2)		-0.611** (3.9)	-0.214 (1.4)	
External R&D, own firm, Other areas, t-2	0.078** (7.5)	0.085** (8.5)	0.090** (9.3)	0.079** (7.6)	0.086** (8.5)
External R&D, own firm, Own area, t-2	0.090** (4.1)	0.097** (4.5)	0.139** (6.4)	0.089** (4.1)	0.095** (4.4)
R^2	0.636	0.636	0.603	0.641	0.641
MSE	1.230	1.231	1.331	1.221	1.223
N	10010	10010	10010	10010	10010

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The results for fixed effects models of Table 3.3 show, however, how coefficient estimates react when certain parts of total variation is eliminated. Industry dummies omit comparisons between industries, which dramatically lowers coefficients for the elasticities of external R&D in the same industry. The impact from other firms' R&D in other areas and in the same industry even turns negative. The estimated coefficients represent the net effect of all positive and negative impacts associated to the explanatory variable in the question. In the case considered, the negative coefficient of other firms' R&D in other areas and in the same industry hints that the tendency to the substitute knowledge capital of this R&D pool for a plant's own R&D dominates. The results in the second column of table 3.3 show that, despite the inclusion of industry dummies, the elasticity for other firms' R&D in the same region remains positive, and the respective elasticity for other areas remains zero. The inclusion of region dummies decreases the positive impact or makes zero impact negative from other firms' R&D in other industries. When both region and industry dummies are included the other firm's R&D in other areas affects negatively on a plant's R&D investments. The other firms' R&D in a plant's own area has then no effect. If the other firms' R&D stock is only sorted into two pools, that part which is located in other areas has a negative impact, whereas the other firms' R&D in the same area seems to have no effect on a plant's R&D investments.

After the inclusion of industry and sub-region dummies the previous results, according to which the impact of the other firms' R&D turns positive when this R&D becomes closer either industrially or geographically, should be reformulated. The industrial proximity of external R&D no longer contributes positively to a plant's current R&D investments. We can still say that nearness in the geographical sense increases the positive impacts of spillovers or makes zero impacts positive.

Fixed and random plant effects models

To be able to estimate also the fixed plant effects models, those observations which emerged only in few periods had to be omitted. Therefore data set A was fallen in size by the cutting off of such plants of which R&D investments emerged in less than four periods. We estimated for this reduced panel data fixed plant effects and random plant effects models. According to Hausman's test, in all the cases the fixed effects model is preferred to the random effects model.

According to the estimates of the random effects model (Table A3), the impact from a plant's own R&D stock, turnover, other firms' R&D which is in the same area and industry, and other firms' R&D which is located in the same area but in other industries, is positive. The elasticity from other firms' external R&D in the same industry and other areas is positive as well. The impact from other firms' R&D in other areas and industries does not deviate from zero. The elasticity for the same firm's R&D - near or far - is positive.

The fixed effects models which utilize within-plant variation does not give any nonzero explanation for other firms' R&D. Turnover has a positive impact. Elasticity for one's own R&D capital is, however, positive. R&D of the same firm's other plants which are located far away is zero. If these plants are located nearby, the elasticity is negative.

In the interpretation of these results one should keep in mind that the data set considered, has, at its maximum, only seven periods, which is not much. In the total variation of the considered data, time variation therefore plays a minor role. Besides, in the years 1985-1997 the Finnish firms went through a deep going structural change which weakens the homogeneity of the group in the fixed effects model, insofar as the group consists of a plant in different time periods. Because, in many cases, a plant in period t is very different from the same plant in period t+1, it is highly critical to compare only the same plant in different periods.

According to one interpretation, within-plant coefficient estimates reflect rather short-run effects (see Bartelsman et al., 1994), whereas, between-plant coefficient estimates can be interpreted as long-run elasticities. Between-plant variation dominates variation in the random effect model as well as in the models reported in Table 3.2.

Public finance

If the private sector would not fund the risky R&D projects, one can expect that the governmental subsidies have a positive impact on R&D investments, whereas in the perfectly behaving capital market public R&D funding has no effect on the marginal costs of the projects and thus on the amount of R&D investments. We shall next analyse more closely, whether public finance affects R&D investments.[4]

We consider the role of public finance, which includes both loans and subsidies from public sources. Public funding is also deflated with the private sector's earnings index. The data set covers now only the years from 1991 to 1998. The characteristics of this data set (data set C) are described in Appendix B. If a firm has several R&D active plants, the firm's public funding is divided between plants in the proportion of the plant's share of a firm's R&D investments. One can argue that this procedure creates spurious correlation between public finance variable and the explanatory variable. According to the estimation results (see Table 3.4) a one percent increase in public finance for R&D increases R&D investments by about 0.5 percent. Estimating the same model for the R&D investments using the firm-level data set, which has not the discussed problem of spurious correlation, we obtain an estimate for the coefficient of public finance variable of 0.45. This is not much less than the respective estimates in Table 3.4. Also the estimates for other coefficients are quite close to the respective estimates of Table 3.4 which shows that spurious correlation does not lead to large biases in the estimated coefficients.

The results from plant-level data set also show that the effects from turnover, its own past R&D stock and external R&D from other firms in the same area still have positive elasticities. The elasticity for the external R&D from other firms which are

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[4] In the literature, the results concerning the effects of public funding on the behaviour of private firms are rather mixed. Klette and Moen (1998a), for example, concluded that public R&D support did not stimulate R&D activities of the firms in the IT-related manufacturing. In another study (1998b) the same authors, however, found out that R&D support did not crowd out private R&D spending, although it did neither increase the firm's own finance of R&D. Niininen (1998) has analysed the effects of public funding using a panel data set of Finnish firms. These results show that subsidized loans induce new R&D more effectively than direct subsidies.

located in the same industry but in other areas is positive. The dilution effect also concerns the external R&D of other firms' plants in the same industry and in other areas. According to this effect, positive spillover loses its power when the number of information sending plants increases.

Table 3.4.

Period 1991-1998
Dependent variable, R&D-investments - Plant-level regression , data set C
OLS

coefficient estimate (t-statistics in parentheses)

	(7)	*(8)*
Intercept	0.334 (0.3)	-1.211 (0.8)
Turnover, t	0.232** (41.7)	0.231** (40.6)
Own R&D, t-2	0.385** (47.5)	0.379** (46.7)
External R&D, own area, own industry, t-2	0.044** (6.2)	0.045** (5.1)
Number of other units, own area , own industry, t-2		0.004 (0.2)
External R&D, other areas, own industry, t-2	0.038** (5.3)	0.070** (6.6)
Number of other units, other areas, own industry, t-2		-0.068** (3.7)
External R&D, own area, other industries, t-2	0.051** (5.7)	0.064** (3.7)
Number of other units, own area, other industries, t-2		-0.011 (0.4)
External R&D, other areas, other industries, t-2	0.223** (3.2)	0.142 (1.8)
Number of other units, other areas, other industries, t-2		0.357** (3.1)
External R&D, own firm, other areas, t-2	0.070** (7.8)	0.116** (10.2)
Number of other units, own firm, other areas, t-2		-0.307** (7.0)
External R&D, own firm, own area , t-2	0.067** (3.5)	0.058** (3.0)
Number of other units, own firm, own area, t-2		0.096 (0.2)
Public finance, t	0.521** (48.6)	0.509** (47.3)
R^2	0.723	0.726
MSE	0.902	0.892
N	7713	7713

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

It is possible that the public finance variable correlates with the residual of the estimated R&D investment equation. This may create bias in the coefficient estimates of the model reported in Table 3.4. For this sake it is reasonable to estimate a model which also contains an equation for public finance. Public finance is either positive or zero. Zero observations are also included in those cases where the actual willingness to obtain public finance or the abilities to get it are far below the point at which a plant almost gets public finance. It is thus natural to define public finance as a censored variable and to model it as a Tobit model so that the censoring point is zero. The Maximum Likelihood estimates for the system of these two equations - one for public funding and another for the R&D investments - are reported in Table 3.5. [5]

[5] In this procedure the cross-correlation between the residuals of the R&D equation and the equation of the latent underlying regression for public finance is taken into account.

Table 3.5.

Period 1991-1998
Dependent variable, R&D-investments - Plant-level regression, data set C
FIML & TOBIT

coefficient estimate (t-statistics in parentheses)

	Public finance Model A	***R&D investments Model A***	***Public finance Model B***	***R&D investments Model B***
Intercept	15.184** (2.6)	7.790** (3.5)	16.756** (3.0)	7.967* (3.8)
Turnover, t		0.225** (47.6)		0.221** (46.7)
Own R&D, t-2	0.660** (17.7)	0.548** (44.6)	0.677** (17.9)	0.559** (44.8)
External R&D, own area, own industry, t-2	0.095** (3.0)	0.068** (5.7)		
External R&D, own area, t-2			-0.039 (1.0)	0.059** (4.0)
External R&D, other areas, own industry, t-2	0.130** (4.0)	0.078** (6.7)		
External R&D, other areas, t-2			-0.892** (2.9)	-0.145 (1.3)
External R&D, own area, other industries, t-2	-0.108** (2.6)	0.011 (0.7)		
External R&D, other areas, other industries, t-2	-0.865** (2.6)	-0.120 (1.0)		
External R&D, own firm, other areas, t-2	0.332** (6.9)	0.200** (11.9)	0.351** (7.2)	0.210** (12.2)
External R&D, own firm, own area, t-2	0.269** (2.7)	0.150** (4.4)	0.251* (2.4)	0.143** (4.0)
Real interest rates, t	-0.042** (2.7)		-0.042** (2.6)	
The share of those having education on tertiary level in research staff, t	0.252** (2.7)		0.210* (2.3)	
Public finance, t		0.225** (20.3)		0.228** (20.4)
N	7714	7714	7714	7714

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The estimated elasticity for public funding obtained from the simultaneous equation model has dropped at the level of 0,2 This hints that the previous estimate of size 0,5 was upward biased. The elasticity of 0,2 corresponds to a situation where 10 percent increase in public funding adds R&D investments on the net about 2 percents. Taking into account that for such plants who have received public R&D funding the mean of R&D investments is 4,85 four times as large as the mean of the received R&D funding, the elasticity of 0,2 (or more exactly 0,225) corresponds to a situation in which ten units increase in R&D funding leads to roughly ten units increase in R&D investments. So, we can say that the new publicly funded R&D does not crowd out privately funded R&D. Neither it adds privately financed R&D investments. This result is quite near the result obtained by Klette and Möen (1998b).

The results reported in Table 3.5 also show that public R&D funding is strongly influenced by a plant's own R&D stock and external R&D in the past. The external R&D of other firms in the same industry has positive impact on public finance. But the effect of other firms' R&D is negative, if it is located in other industries, especially when plants are also located in other sub-regions. The negative elasticity - which reflects the net effects of all kind of effects - hints that that there might be a kind of battle between firms for public finance. This result is confirmed by the estimates of the model, presented in the third and fourth columns of Table 3.5, in which external R&D is sorted into two pools only: one which is geographically near and another which is far. All in all, the results tell us that public intervention in the form of public funding also strongly shapes the regional distribution of R&D activity. But we do not know whether this intervention works for concentration or against it.

The estimates for the impacts of R&D in the considered simultaneous equation model do not bring the new results which would give us reason to reverse earlier conclusions. Yet, other firms' R&D regains its positive power when it comes closer in both the geographical and technological sense.

The results also show that the amount of public finance received positively depends on the research staff's education. The larger the share of those having education at the tertiary level is, the larger is public finance for R&D. When the other firms' external R&D is sorted only into two pools (Model B in Table 3.5), the estimated elasticities for the other firms' external R&D stock clearly prove that short geographical distance reinforces the positive spillover effects.

Firm-level approach

In the firm-level data (data set E) R&D stocks are generated at the firm-level (see chapter 2). In the firm-level data no R&D capital is lost, if a single plant dies off in so far as the firm keep on its living. In calculating external R&D pools a firm's R&D stock is divided between sub-regions following the distributions given by the plant-level data. In the firm-level data each firm's home area is determined to be those sub-regions where a firm has plants with positive R&D stock.

Table 3.6.

Dependent variable, R&D-investments - Firm-level regression, data set E
OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*
Intercept	9.088** (6.6)	9.311** (6.8)
Turnover, t	0.235** (37.6)	0.239** (38.0)
Own R&D, -2	0.529** (59.6)	0.528** (59.6)
External R&D, own area, own industry, t-2	0.056** (7.5)	0.056** (7.5)
External R&D, other areas, own industry, t-2	0.035** (4.5)	0.034** (4.5)
External R&D, own area, Other industries, t-2	0.016 (1.7)	-0.015 (1.3)
External R&D, other areas, Other industries, t-2	-0.256** (3.5)	-0.253** (3.5)
The number of own units, t-2	-0.126* (2.3)	-0.133* (2.5)
Dummy for the location of a university		0.206** (5.3)
R^2	0.613	0.614
MSE	1.300	1.296
N	8273	8273

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The estimated coefficients from firm-level data are reported in Table 3.6. In spillover effects the positive impact of that part of other firms' R&D which is in the same sub-region and in the same industry is emphasized. Spillover from other regions but from the same industry is still positive. But the elasticity for other industries is zero. The effect from external R&D in other sub-regions and industries is even negative, which hints again at the possible adverse effects which arise, if the firms substitute external R&D for own R&D. According to the results the increase in the number of a firm's own R&D active plants lessens the incentives to invest in R&D. When one interprets this result it should be noticed that a firm with many plants has a relatively large pool of external R&D which is near both geographically and industrially. The positive impact on the R&D investments of this pool is therefore remarkably. As a reaction for this, the increase in the number of those units which gather knowledge spillover for a large firm decreases R&D investments.

The elasticity for university research in the fields of technology and data-processing has turned out to be zero in most of the experiments. The inclusion of a dummy which describes the location of a university in those sub-regions in which a firm is operating has, however, a positive impact on current R&D investments, although this kind of permanent effect is, at least partly, incorporated by the lagged R&D stock variable. These results hint, however, that it is rather the universities' role in educating people and in generating a local supply of high-skill labour which explains this impact on R&D investments rather than the knowledge spillovers from a university to local firms.

New units and small units

One could think that for small and new units the distance in every sense matters more than it does for large units. In Table 3.7 we have reported the results from regression which uses data set A and in which the estimated coefficients are corrected by the dummy for new plants. The second column of this table shows how much the estimated coefficients change when new plants are concerned. The changes in the coefficient of turnover and public finance deviate from zero statistically significantly. The estimated elasticity for public finance for new plants is higher than for old plants. This shows that public finance is more effective in generating new R&D activity among new plants than among old plants.

Table 3.7.

Dependent variable, R&D-investments - Plant-level regression, data set E.
Periods 1987-1998
OLS,

(t-statistics in parentheses)

$R^2 = 0.733$ MSE=0.872 N=7713

	Coefficient for old plants	*A dummy for new plants*
Intercept	2.529 (1.8)	-
Turnover, t	0.192** (29.2)	0.128** (11.7)
Own R&D, t-2	0.424** (47.5)	-
External R&D, own area, own industry, t-2	0.035** (5.0)	0.012 (1.5)
External R&D, other areas, own industry, t-2	0.035** (4.7)	0.008 (0.6)
External R&D, own area, other industries, t-2	0.049** (5.0)	-0.018 (0.8)
External R&D, other areas, other industries, t-2	0.129 (1.7)	0.254 (1.5)
External R&D, own firm, other areas, t-2	0.076** (8.6)	-0.009 (1.2)
External R&D, own firm, own area, t-2	0.065** (3.4)	0.018 (1.1)
Public finance, t	0.486** (44.8)	0.101** (9.2)
Dummy for new plant		-5.240 (1.74)

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Then the data set A is divided into two parts. One part consists of those observations in which a plant's own past R&D stock is below the average, and another part consists of those observations in which a plant's own past R&D stock is above the average. These two blocks are called small investors and heavy investors. We have estimated the standard model of R&D investments for both these blocks. The results are reported in Table 3.8.

Table 3.8.

Period 1987-1998

Dependent variable, R&D-investments - Plant-level regression, data A divided into parts
OLS

coefficient estimate (t-statistics in parentheses)

	Small investors	***Small investors***	***Heavy investors***	***Heavy investors***
Intercept	1.035 (0.6)	0.296 (0.2)	1.968 (1.1)	2.592 (1.3)
Turnover, t	0.235** (31.9)	0.234** (31.5)	0.177** (17.5)	0.176** (16.9)
Own R&D, t-2	0.477** (27.5)	0.456** (26.4)	0.744** (47.4)	0.738** (46.9
External R&D, own area, own industry, t-2	0.064** (6.1)	0.062** (4.6)	0.015 (1.5)	0.029* (2.3)
Number of other units, own area , own industry, t-2		0.009 (0.3)		-0.058 (1.7)
External R&D, other areas, own industry, t-2	0.052** (5.2)	0.089** (6.1)	0.051** (4.9)	0.059** (3.8)
Number of other units, Other areas, own industry, t-2		-0.082** (3.1)		-0.009 (0.3)
External R&D, own area, Other industries, t-2	0.054** (4.7)	0.054* (2.5)	0.033* (2.5)	0.016 (0.6)
Number of other units, own area, Other industries, t-2		-0.007 (0.2)		0.037 (1.0)
External R&D, other areas, Other industries, t-2	0.192* (2.0)	0.181 (1.6)	-0.084 (0.8)	-0.160 (1.3)
Number of other units, other areas, Other industries, t-2		0.129 (1.3)		0.092 (0.9)
External R&D, own firm, Other areas, t-2	0.093** (6.2)	0.210** (11.2)	0.066** (5.6)	0.112** (7.2)
Number of other units, own firm, Other areas, t-2		-0.798** (11.1)		-0.267** (4.7)
External R&D, own firm, own area , t-2	0.247** (6.1)	0.238** (5.9)	0.087** (3.2)	0.062* (2.3)
Number of other units, own firm, own area, t-2		-0.978 (1.3)		0.844 (1.7)
R^2	0.316	0.316	0.613	0.616
MSE	1.553	1.520	0.923	0.916
N	6454	6454	3555	3555

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The plant's own R&D stock seems to be a more important basis for R&D investments for heavy investors than for small investors. The external R&D stock of other firms in a plant's own area - both in the same industry and in other industries - contribute much more to small investors' R&D investments than to heavy investors’ R&D investments. The other firms’ past R&D stocks in the same industry and in other areas is about equally important for both blocks. The dilution phenomenon is much more considerable for small investors than for heavy investors. This shows that the small players’ capacity to receive knowledge from many sources at the same time is very limited. This dilution effect also concerns the knowledge transfer from the firm’s other plants which are located in other sub-regions. On the whole, these results imply that the small investors' R&D investments are much more influenced by geographical distance than the heavy investors' R&D.

4. R&D AND PRODUCTIVITY

4.1. On the theory of the spillover effect and the empirical model

A firm's own R&D improves the firm's economy in two ways. It gives temporary monopoly power to widen the price-cost margin and, on the other hand, it increases a firm's productivity. External R&D in the form of spillovers or through co-operation based on voluntary agreements has parallel effects. It already follows from theory that the effect of external R&D on productivity is quite unambiguously positive. The possible substitutability of R&D assets or effects which appear via changes in the competition situation do not create such downward pressures on productivity as they do on R&D investments. However, through imperfectly behaving markets of the factors of R&D negative impacts can also arise. If a group of firms hire the best employees or get a great part of public R&D support, the possibilities for the rest of the firms to improve their efficiency following a common trend may weaken.

In the productivity analysis we also test whether geographical and technological proximity matter. Technological proximity is though approximated by industrial proximity. The regional aspect of productivity in Finland has already been tackled by Maliranta (1999), who has found that relatively new and relatively old firms' productivity correlates closely with other firms' productivity in the same region, which refers to the possible existence of spillovers.

In the literature there is a wealth of studies which test the effect of a firm's own R&D on productivity. Husso et al. (1996), in their study which uses Finnish data, a 1987-1993 panel of 74 firms, report that the estimate for R&D capital elasticity is 0.08. Lehtoranta (1998), who uses data for 186 Finnish firms from the years 1991-1994, obtained a similar result with elasticity of the size of 0.06. These results from Finnish data do not deviate much from results obtained in many studies which use foreign data. For example, Dilling-Hansen et al. (1999), who use Danish data, report the estimates for R&D capital elasticity as being roughly 0.08 when so-called double counting (a consequence of simultaneous inclusion of R&D factors in labour and R&D stock) is corrected.

The spillover effects of R&D are also examined with the Finnish data. Rouvinen (1999) has estimated a translog cost function and defined R&D stock as quasi-fixed input. The data of this study cover 437 firms from the period 1985-1997, 2753 observations altogether. Rouvinen (1999) found that a 1 percent increase in intra-industry stock (of external R&D) reduces firms' variable costs by 0.01 percent. The respective spillover effect for inter-industry stock was 0.03 percent. These results refer to the fact that there are positive spillover effects, but that industrial proximity does not seem to matter. On the contrary, the effects from other industries are stronger than from the firm's own industry.

Orlando (1999) analyses inter-firm spillovers using US data for industrial and commercial machinery and equipment firms. The data comprise 498 firms from the years 1971-1996. Orlando (1999) estimates the extended Cobb-Douglas production function and sorts external R&D stock according to its geographical and technological location. Another firm is near if it is located within 25 miles radius and within one's own 4-digit SIC. The results show that both technological and geographical distance attenuates spillovers from innovative activity. The reported elasticity for own R&D capital in this study is rather small, 0.015, when external R&D stock sorted by both technological and geographical location is controlled. The low elasticity for a firm's own R&D can follow from the inclusion of external R&D stock variables. Adams and Jaffe (1996) also consider the effects of technological and geographical distance. Due to data limitations they cannot test technological and geographical proximity simultaneously. They focus on intra-firm spillovers. According to them, proximity seems to matter, but the increase in the number of other firms who send spillovers or in the number of the firm's own plants who receive information concerning innovations dilute the spillover effects. Adams and Jaffe (1996) interpret this effect as reflecting the limitations for knowledge capital to act as a source of industry-wide increasing returns.

There are two alternative approaches to analyse empirically R&D: the response of productivity to a plant's own R&D activity and R&D spillovers. The first tradition takes as its starting point the conventional Cobb-Douglas or CES production function (see e.g. Adams and Jaffe (1996), Fors (1997), Dilling-Hansen et al. (1999) and Orlando (1999)). One advantage of this approach is that it calculates elasticities directly, which makes an interpretation easy and clear. The other approach estimates the translog total cost function from which an estimate for R&D impact is derived (see e.g. Bernstein and Nadiri, 1988 and 1989). See also Rouvinen (1999), who has analysed R&D spillovers thorough a cost function approach using Finnish data. The latter approach also takes into account the changes in factor demand.

It must be noticed that in the productivity analysis a firm's sales (or nominal value added) are commonly deflated by industry's producer price index, as in our study. Because a single firm's prices can, however, deviate from an industry-specific pattern, a pure productivity change cannot be separated from the mentioned price margin effect. Therefore, the test which measures R&D's productivity effect also takes into account partly the widening of the price-cost margin and its effects on profitability.

For the time being we have followed the first approach, which extends the Cobb-Douglas production function with R&D stocks.

In Cobb-Douglas technology, plant i's output has the equation

(6) $$Q_{i,t} = e^{c} e^{\lambda t} L_{i,t}^{\alpha} K_{i,t}^{\beta} R_{i,t-2}^{\gamma} \prod_{j=1}^{k} ER_{i,j,t-2}^{\delta_j} \prod_{j=1}^{k} N_{i,j,t-2}^{\eta_j} e^{\varepsilon_{i,t}} .$$

where

Q = value added, fixed price

c = constant

t = time trend

L = labour input, hours

K = stock of physical capital

R = own R&D stock

ER_j = external R&D stock in the j'th pool

N_j = the number of those whose R&D stock in the j'th pool is above zero

ε = an error term.

The elasticities α, β, γ and δ_j, η_j relate to the four factors of production. The above function is estimated in log-form

$$(7) \qquad q_{i,t} = c + \lambda t + \alpha l_{i,t} + \beta k_{i,t} + \gamma r_{i,t-2} + \sum_{j=1}^{k} \delta_j er_{i,j,t-2} + \sum_{j=1}^{k} \eta_j n_{i,j,t-2} + \varepsilon_{i,t} \,,$$

where the small letters denote logs of variables. Above the logs taken from all R&D variables and from $N_{i,t}$ is log(x+1).

4.2. The estimation results

Basic models

The basic data set of productivity analysis consists of two basic data sets. The data for fixed price value added, labour input (hours and the number of persons) and capital stock have been collected from industrial statistics data by Mika Maliranta. This data set is combined with the same R&D data which were also used in the analysis of R&D investments. The combined data set includes the plants only of manufacturing firms. All those firms of industrial statistics data are included in the combined data set, which are also included in the large data set of R&D stocks. All the plants of those firms which remain in this data set are then included. External R&D is then specified for all plants. In this calculation we have used the large data set for R&D stocks. Practically all the R&D active firms in Finland have then been taken into account.

The results of Table 4.1 show that both a plant's own R&D and external R&D contribute to the plants' productivity. The first column of this table shows the basic results. The estimated elasticity for a plant's own R&D is about half or even less than in the previous research which uses the Finnish data. If all spillover variables are omitted (see the model of column 5) the estimate in question becomes 0.06, which is exactly the same as the estimate for this elasticity obtained by Lehtoranta (1998). All in all, it looks as if the previous estimates are upward biased owing to the absence of external R&D variables.

The estimates of models (1)-(5) in Table 4.1 are based on the data which covers the years 1987-1998. The model (6) does not include 1998.

Table 4.1.

Dependent variable, fixed price value added - Plant-level regression, data set D

OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Intercept	5.744** (8.7)	5.488** (8.2)	5.543** (8.8)	4.719** (5.7)	4.436** (126.8)	4.796** (6.7)
Time trend	0.063** (22.0)	0.063** (21.8)	0.063** (22.6)	0.053** (11.1)		0.052** (15.2)
Labour input, t	0.729** (95.5)	0.801** (162.0)	0.728** (95.5)	0.733** (94.5)	0.722** (90.9)	0.737** (89.7)
Capital input, t	0.200** (40.6)	0.199** (40.1)	0.204** (41.79	0.195** (39.3)	0.222** (44.6)	0.196** (37.2)
The share of tertiary education of the whole staff, t						1.011** (11.5)
Own R&D, t-2	0.033** (5.7)	0.014* (2.4)	0.037** (6.3)	0.032** (5.5.)	0.059** (9.6)	0.019** (2.8)
External R&D, own area, own industry, t-2	0.024** (4.3)	0.021** (3.9)		0.024** (3.6)		0.014* (2.3)
Number of other units, own area , own industry, t-2				0.029 (1.0)		
External R&D, own area, t-2			0.016** (3.8)			
External R&D, other areas, own industry, t-2	0.024** (6.1)	0.022** (5.4)		0.047** (8.4)		0.020** (4.6)
Number of other units, other areas, own industry, t-2				-0.076** (6.1)		
External R&D, own area, other industries, t-2	0.014** (3.4)	0.014** (3.3)		0.032** (4.4)		0.014** (3.1)
Number of other units, own area, other industries, t-2				-0.033* (2.5)		
External R&D, other areas, t-2			-0.095* (2.5)			
External R&D, other areas, other industries, t-2	-0.101* (2.5)	-0.101* (2.5)		-0.125** (2.7)		-0.045 (1.0)
Number of other units, other areas, other industries, t-2				0.215** (4.4)		
External R&D, own firm, other areas, t-2	0.041** (8.0)	0.034** (6.6)	0.042** (8.3)	0.050** (7.3)		0.025** (4.4)
Number of other units, own firm, other areas, t-2				-0.083** (2.6)		
External R&D, own firm, own area, t-2	-0.025 (1.8)	-0.029* (2.0)	-0.027 (1.9)	-0.031* (2.2)		-0.048** (3.2)
Number of other units, own firm, own area, t-2				0.700* (2.1)		
R^2	0.779	0.776	0.778	0.780	0.756	0.775
MSE	0.529	0.529	0.533	0.526	0.584	0.536
N	11526	11526	11526	11526	11526	10060

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The estimated elasticities for other firms' R&D show that spillovers from a plant's own industry - located in the same or other regions - are positive. But the elasticity for other firms' R&D in the same area and other industries is positive as well. If the other firms' R&D is split into two parts, one of which is located in the same sub-region and the other is located in other sub-regions, only the spillover from a pant's own area has a positive impact. The elasticity for the R&D pool in other areas is even negative.

Only the impact on productivity from other firms' R&D in other areas and industries is not positive. There is weak statistical evidence that this impact is rather negative than zero, indicating that the other firms' R&D may also create adverse effects on a firm's productivity. These negative impacts may arise through factor markets. The elasticity for the R&D of a firm's other plants is also positive insofar as these plants are located in other areas.

When one evaluates the productivity impacts of various past R&D stocks, the absolute size of these stocks should also be noticed. The mean size of a plant's own past R&D stock is about one third of the other firms' R&D in the same area and in the same industry, whereas the other firms' R&D in the same industry and in the other areas is about 9,6 times larger than the other firms' R&D which is near both industrially and geographically. Given the elasticities of the first column in table 4.1, we can calculate that a given change in productivity requires that the other firms' R&D in the same area and in the same industry should increase 4,3 times more than a plant's own R&D, whereas the other firms' R&D, which is located in other sub-regions and in the same industry, should increase 41,6 times more than a plant's own R&D stock.

The second column of Table 4.1. describes estimation results when the coefficients of labour input and capital are restricted to be one in all and thus correspond to constant returns to the scale situation. This restriction especially decreases the estimated elasticity for a plant's own R&D stock. According to the F-test, the sum of the coefficients for labour and capital inputs deviate, however, from one.

The third column of Table 4.1. shows that the positive spillover from other areas and a plant's own industry or from a firm's other plants in other areas are severely weakened when the number of R&D active plants increases in these spillover pools. This same dilution effect - although on a much smaller scale - is also present in the spillover concerning other firms' R&D in the same area and other industries. The dilution impact also weakens the negative impact from external R&D in other areas and other industries. In all the cases the sign of the net effect - which consists of the impacts of actual R&D stock and the number of R&D active plants in the R&D pool considered - is determined by the coefficient of R&D stock variable for almost all the observations. For example, the net effect of the other firms' R&D, which is located in other areas and industries, is negative almost always.

The sixth column of Table 4.1 also includes an education variable. This variable is firm-specific, which means that its value is the same for all a firm's all plants in each year. The data for the model which includes an education variable does not include the year 1998. The results show that productivity increases in the share of those of the whole staff who have had education at the tertiary level. Education level is, however, partly determined by the plant's R&D strategy. Therefore due to the inclusion of education level as an exogenous variable the estimates for own and external R&D may become downward biased. In fact, the elasticity for spillovers in own area decreases after education level is controlled. Spillover from a firm's own units in the same area becomes strongly negative, for which it is difficult to find any sensible explanation.

We estimated also a simultaneous equation model in 2SLS method. This model includes also an equation for labour input. Labour input was made endogenous in order to eliminate the possible bias in the estimated elasticities owing to the correlation between the error term of the R&D investment equation and the labour input. The estimated coefficients of the productivity equation in the two equation model do not, however, differ from the respective coefficients of the one equation model. The estimation results are not therefore reported.

Fixed industry and sub-region effects models

In Table 4.2 we have reported estimation results from the fixed industry and sub-region effects models. The inclusion of 104 industry dummies removes the variation between industries. As a result of this, the elasticity for other firms' R&D in other regions and in a plant's own industry becomes zero. The spillovers from a plant's own area - in the same industry or in other industries - still have a positive impact. The elasticity for a plant's own R&D has remained at 0.03. Negative impact from other firms' R&D in other areas and other industries has become zero as well. In the fixed industry effects model the elasticity for a firm's other plants' R&D in other areas is still positive.

Table 4.2.

Period 1987-1998
Dependent variable, fixed price value added - Plant-level regression, data D
Fixed effects models, GLS

coefficient estimate (t-statistics in parentheses)

	104 industry dummies	***87 sub-region dummies***	***87 sub-region and 180 industry dummies***
Intercept	5.299** (7.4)	10.743** (7.2)	8.505** (5.6)
Time trend	0.061** (21.1)	0.079** (16.5)	0.073** (15.2)
Labour input, t	0.783** (92.5)	0.732** (94.5)	0.782** (91.4)
Capital input, t	0.160** (28.6)	0.195** (39.3)	0.158** (28.1)
Own R&D, t-2	0.031** (5.2)	0.031** (5.3)	0.029** (4.8)
External R&D, own area, own industry, t-2	0.013* (2.3)	0.021** (3.7)	0.011* (2.0)
External R&D, other areas, own industry, t-2	-0.001 (0.1)	0.020** (4.9)	-0.002 (0.2)
External R&D, own area, other industries, t-2	0.016** (3.8)	-0.003 (0.3)	-0.011 (1.2)
External R&D, other areas, other industries, t-2	-0.036 (0.9)	-0.422** (4.7)	-0.255** (2.8)
External R&D, own firm, other areas, t-2	0.028** (4.6)	0.037** (7.1)	0.028** (4.6)
External R&D, own firm, own area, t-2	-0.026 (1.8)	-0.022 (1.6)	-0.026 (1.9)
R^2	0.795	0.785	0.800
MSE	0.496	0.518	0.487
N	11526	11526	11526

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

When the regional dummies are included, the results change from those reported in Table 4.1 much less than after the inclusion of industry dummies. All in all, the inclusion of sub-region and industry dummies only reinforce the conclusion according to which the short geographical distance especially amplifies the positive spillover effect from other firms' R&D.

Fixed and random effects models

Then the basic data set for productivity analysis, data set D (see description in Appendix B), is reduced to cover only those plants that exist in data during at least four periods.[6] This longitudinal panel data set is used to estimate both fixed and random plant effects models. According to Hausman's test the fixed plant effects model should be preferred to the random plant effects model. The results are reported in Table A4 in Appendix A. For the same reasons as in the R&D investment analysis, it is not very sensible to base the analysis on only time variation. Therefore one should take up a sceptical attitude towards the results corresponding to the fixed plant effects model.

According to the results the elasticity for a plant's own R&D, for other firms' R&D in a plant's own industry - both in the same area and in other areas - is positive in the random effects model. The elasticity for external R&D in the same area and in the same industry is, however, much bigger than the respective elasticity for external R&D in the other areas and in the same industry. The spillover from other firms' R&D in other areas and other industries is also negative in this model. The elasticity for other firms' R&D in the same area and in other industries as well the elasticity for a firm's other plants' R&D in the same area has become zero. All in all, these results do not give reason to reverse previously drawn conclusions concerning the relevance of geographical and technological proximity.

Even a plant's own R&D does not seem to have nonzero productivity impact in the estimated fixed effects model which only takes into account within-plant variation. Positive impact is found only in spillover from other firms' R&D in the same area and industry. But there is still negative impact associated with the spillover from other firms' R&D in other areas and other industries.

[6] This is a technical necessity for the estimation of the fixed plant effect model.

Division to small and large firms

Finally, we split the data in two parts. The first part includes those plants of which the parent firm's staff size is below average, and the second part includes the large firms on the basis of staff size.

Table 4.3.

Period 1987-1998
Dependent variable, fixed price value added - Plant-level regression, data D set divided into parts
OLS

coefficient estimate (t-statistics in parentheses)

	Small firms	***Small firms***	***Large firms***	***Large firms***
Intercept	6.215** (7.9)	4.936** (5.1)	5.600** (5.2)	4.883** (3.7)
Time trend	0.064** (18.6)	0.053** (8.9)	0.065** (14.1)	0.056** (7.4)
Labour input, t	0.756** (66.0)	0.761** (65.3)	0.685** (64.1)	0.690** (63.8)
Capital input, t	0.161** (25.9)	0.156** (24.9)	0.221** (29.4)	0.217** (2.2)
Own R&D, t-2	0.040** (4.7)	0.038** (4.5)	0.022* (2.5)	0.020* (2.2)
External R&D, own area, Own industry, t-2	0.016* (2.5)	0.011 (1.3)	0.033** (3.7)	0.038* (3.7)
Number of other units, Own area , own industry, t-2		0.051 (1.4)		0.005 (0.1)
External R&D, other areas, Own industry, t-2	0.024** (5.3)	0.050** (7.6)	0.018** (2.7)	0.034** (3.6)
Number of other units, Other areas, own industry, t-2		-0.085** (5.7)		-0.053* (2.6)
External R&D, own area, Other industries, t-2	0.018** (3.6)	0.021* (2.5)	0.005 (0.7)	0.038** (3.2)
Number of other units, own area, Other industries, t-2		-0.004 (0.3)		-0.063** (2.9)
External R&D, other areas, Other industries, t-2	-0.130* (2.7)	-0.123* (2.3)	-0.082 (1.2)	-0.139 (1.9)
Number of other units, other areas, Other industries, t-2		0.179** (3.0)		0.241** (3.2)
External R&D, own firm, Other areas, t-2	0.070** (5.1)	0.075** (5.1)	0.031** (4.9)	0.038** (4.4)
Number of other units, own firm, Other areas, t-2		-0.178 (1.4)		-0.064 (1.7)
External R&D, own firm, Own area , t-2	-0.045 (1.4)	-0.040 (1.2)	-0.027 (1.5)	-0.034 (1.8)
Number of other units, own firm, Own area, t-2				0.629 (1.7)
R^2	0.708	0.710	0.767	0.768
MSE	0.394	0.391	0.640	0.637
N	5647	5647	5880	5880

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

It is quite surprising that the elasticity for a plant's own R&D is bigger for small than large firms. Spillovers from a plant's own area and industry seem to be much more important to large firms than to small firms. The productivity of small firms is favoured especially, on the one hand, by external R&D in a plant's own area and other industries and, on the other hand, in the other areas and in the same industry. The adverse effect from other firms' R&D in other areas and in other industries hurts small firms more than large firms. This may indicate that small firms suffer more than large firms from the R&D factor market imperfections.

The small firms' productivity seems to decrease when the number of those remote firms in the same industry from which R&D knowledge is received increases. But for the large firms this dilution effect is relatively strong with respect to external R&D in a plant's own area and in other industries.

5. R&D AND EMPLOYMENT

In this chapter we focus on employment. In previous sections it has been found that both geographical and industrial proximity matters in the determination of R&D investments and productivity. It is not clear that this same pattern holds good when employment is concerned. R&D can affect employment in various ways. One would expect that a plant's own R&D increases the plant's total employment. But even this hypothesis can be opposed by insisting that through increased efficiency a plant's own R&D especially decreases the demand for low-skill labour and thus also a total demand of labour.

External R&D can affect employment at least through spillovers and through labour market interactions. R&D spillovers typically reinforce R&D investments and high-skill activities which are in the same industry or in the same area. Because the efficiency gains also offer an opportunity to reduce low-skill labour, the effect on total employment is, however, unclear. By affecting labour supply, external R&D can also have a clear negative impact on a firm's or a plant's total employment. Heavy R&D investments in other firms also require a lot of high-skill labour whose supply, therefore, reduces a firm's or a plant's opportunities to hire labour. These supply restrictions are particularly relevant for high-skill labour.

It is still possible that a plant's own R&D or external R&D in its own area indirectly strengthens the opportunities to enlarge low-tech industries in other areas. The increased demand for high-skill labour may raise local cost of living and in this way improve the competitiveness of other areas especially in low-skill activities. Also, the relative immobility of labour - for various reasons - sustains the supply of labour at a relatively high level in those areas especially in which labour is not employed by R&D activities.

We analyse employment effects using two separate data sets. First, we consider the data set which is basically the same as the data set of productivity analysis (data set

D). Then we analyse the data set which is almost the same as data set B, the large data set for R&D investment analysis. This data set also includes zero observations for current R&D investments.

In the first data set the number of observations fell from 11 527 to 10 555, due to the inclusion of a new variable, a lagged staff size variable. In the constructed model the current size of personnel is explained both with the past size of personnel and R&D stocks. R&D stocks are still lagged with two years. The observations consist of all the plants of those manufacturing firms which are included in the R&D surveys of Statistics Finland. The second data set includes all industry branches, and the service sectors. But this data set excludes such locations and such plants of the firms with positive R&D stock that have not invested in R&D. This data set includes only the firm characteristics and the principal place of business of those firms that have responded to the R&D survey and announced that R&D investment is zero.

A plant i's current employment is assumed to follow a simple model

$$(8) \qquad L_{i,t} = e^{c} L_{i,t-2}^{\mu} R_{i,t-2}^{\gamma} \prod_{j=1}^{k} ER_{i,j,t-2}^{\delta_j} \prod_{j=1}^{k} N_{i,j,t-2}^{\eta_j} G^{\omega} e^{\varepsilon_{i,t}} .$$

where

- c = constant
- L = labour input, number of employees
- R = own R&D stock
- ER_j = external R&D stock in the j'th pool
- N_j = the number of those whose R&D stock in the j'th pool is above zero
- G = real GDP
- ε = an error term.

GDP variable in the above model captures the effect of the general economic situation which affects employment in all the firms. The above function is estimated in log-form

(9) $$l_{i,t} = c + \mu l_{i,t-2} + \gamma r_{i,t-2} + \sum_{j=1}^{k} \delta_j er_{i,j,t-2} + \sum_{j=1}^{k} \eta_j n_{i,j,t-2} + \omega g + \varepsilon_{i,t},$$

where the small letters denote logs of variables. Above the logs taken from all R&D varibles and from $L_{i,t-2}$ is log(x+1). The estimation results are reported in Table 5.1.

Employment in manufacturing

According to the estimation results based on data set D, which covers only the manufacturing industries, the elasticity for past employment is one. Therefore, the models above implicitly explain the relative changes in employment. We have used as a regressor a firm's own past R&D stock in the same municipality where the plant in question is located. To avoid the effects of spurious correlation, a firm's R&D stock is no longer divided between the plants in the municipality in proportion to a plant's current employment share.[7] As a regressor we have used also the number of a firm's plants in the municipality. A firm's own past R&D stock in the same municipality seems to have no effect on a plant's total employment. This shows that despite the need of additional R&D personnel, R&D activity which raises productivity lets the firms also to reduce the other personnel. The net effect is then zero. The estimation results from the other data set - which is used in the analysis of R&D investments and which also covers the service industries - say that an increase in a plant's own R&D increases its total employment. The differences between these results may be partly explained by the particular behaviour R&D intensive service firms, and partly by the characteristics of the data.

The other firms' R&D which is located in the same industry (see model in column (1)) - whether in the same sub-region or in other sub-regions - has a positive effect

[7] In the productivity analysis the multi-plants' own R&D stock in the years 1995-1998 was constructed in this way. It appeared, however, that the estimated elasticity for a plant's own R&D was almost the same even if the constructed plant-level variable was replaced for a firm-level variable.

on employment. The elasticity for the other firms' R&D stocks in other industries seems to be negative. The positive employment effect thus requires industrial proximity. The negative impact which arises if firms invest in R&D in other industries can be interpreted to reflect the labour market effects. The estimations results of the model in the first column hint that the geographical distance does not matter. This outcome together with the previous result which states that geography is important in the determination of R&D investments can be seen as an outcome of geographical specialisation. In fact, on the basis of Figure 2 and Table 3.1 we have already concluded that geographical distributions of R&D or production depart from each other (see also Kelly and Hageman, 1999).

Table 5.1.
Period 1987-1998
Dependent variable, number of employees - Plant-level regression.
Based on data set D, OLS coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*
Intercept	-3.549** (5.6)	4.350** (3.2)	-3.743** (6.0)	4.362** (3.2)
Number of employees, t-2	1.000** (321.3)	1.000** (321.9)	1.001** (322.0)	1.001** (322.6)
Own R&D, t-2	-0.002 (0.6)	-0.015 (0.7)	0.0003 (0.1)	-0.001 (0.3)
Number of plants which share past R&D stock	-0.016* (2.1)	-0.015* (2.0)	-0.014 (1.9)	-0.013 (1.7)
External R&D, own area, own industry, t-2	0.008** (2.8)	0.011** (3.1)		
Number of other units, own area , own industry, t-2		-0.024 (1.6)		
External R&D, own area, t-2			-0.002 (0.9)	-0.006 (1.5)
Number of other units, own area t-2				0.009 (1.3)
External R&D, other areas, own industry, t-2	0.008** (3.9)	0.002 (0.7)		
Number of other units, other areas, own industry, t-2		0.019** (3.0)		
External R&D, own area, other industries, t-2	-0.005* (2.4)	-0.007* (2.0)		
Number of other units, own area , other industries, t-2		0.008 (1.1)		
External R&D, other areas, t-2			-0.049** (3.2)	-0.134** (6.3)
Number of other units, other areas, t-2				0.215** (6.4)
External R&D, other areas, other industries, t-2	-0.043** (2.8)	-0.135** (6.2)		
Number of other units, other areas, other industries, t-2		0.202** (6.1)		
External R&D, own firm, other areas, t-2	0.002 (0.9)	-0.001 (0.2)	0.002 (0.9)	-0.002 (0.5)
Number of other units, own firm, other areas, t-2		0.023 (1.4)		0.029 (1.8)
External R&D, own firm, own area, t-2	0.008 (1.0)	0.009 (1.2)	0.008 (1.1)	0.009 (1.2)
Number of other units, own firm, own area, t-2		-0.322 (1.9)		-0.370* (2.2)
Real value of GDP	0.537** (10.6)	-0.053 (0.5)	0.560** (11.1)	-0.052 (0.5)
R^2	0.921	0.921	0.921	0.921
MSE	0.137	0.136	0.137	0.137
N	10955	10955	10955	10955

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

The inclusion of the frequencies of those units which are active in R&D (colum 2 of Table 5.1) did not alter the basic results, whereas the estimation of models in which the other firms' R&D stock is divided into only two pools - one which includes R&D in the same area and another which includes R&D in other areas - reveals that geographic distance does matter. A large stock of R&D in other areas which attaches a lot of labour seems to have a negative impact on a plant's total labour. It is difficult to find for this phenomenon any explanation that is not associated with the bottlenecks in labour supply. The inclusion of frequency-variables shows (see column 4 in Table 5.1) that the negative net impact linked to the external R&D in other areas weakens with the number of R&D active units in this R&D pool.

The estimation results of the fixed industry and sub-region effect models, which are reported in Table A6, support the previous conclusions. It looks as if the geographical distance does not matter so much. Only when the frequency variables are included the external R&D which is remote has a negative net impact on total employment. This effect becomes weaker when the number of the other firms, who are active in R&D, increase.

Employment in all the industries

Estimation results based on data set B are reported in Table A5 in Appendix A. This data set includes all the private industry branches, the services also. According to the results of Table A5 the elasticity for a plant's own R&D is statistically different from zero and about 0.06. Using the firm-level data set (data set E), in which all the observations of staff size are obtained directly from Business Register or R&D survey, the obtained elasticity for the firm's own R&D is even larger (and statistically different from zero) than in the plant-level analysis. This shows that positive elasticity obtained in the plant-level analysis is not the result of the way in which the plant-level staff size variable is constructed.[8]

[8] In section 2 it is explained how staff size variable of the data set considered is constructed. The used procedure overestimates a staff size of multi-plant firms in the years 1995-1998. Besides, the distribution of current R&D investments is used approximate the staff size for these observations.

Many differences between the results in Table 5.1 and in Table A5 are explained by the differences in the data. Perhaps, the behaviour of service industries explains a big part of this difference. A part of this difference may be explained by the exclusion of many plants that are not active in R&D. The estimated coefficient for the lagged employment in the models of Table A5 are around 0.9 and thus considerably below one, implying that there is a decreasing trend in employment. By using as an explanatory variable the change of employment - which fixes the coefficient of the lagged employment on one - instead of the level of employment, has also remarkable impact on the estimated elasticity for a plant's own R&D. The elasticity concerned decreases from 0.56 to only 0.016. The estimate is still, however, statistically different from zero.

A positive impact associated with other firms' R&D in the same industry arises in the models only of Table A5, if also frequency variables are also included (see columns 2 and 4). The estimation results show that the positive employment impacts dilute with the number of those units from which technological knowledge is received. A strong negative employment impact related to R&D in other industries and in other areas or in other areas alone is still present. In the results of Table A5 the negative impact of the external R&D in other industries and in other industries become emphasized.

The eliminating the variation between industries or sub-regions has hardly any effect on the previous results. In the fixed industry and sub-region effect models which are reported in Table A7, the other firms' R&D in the other sub-regions has still negative impact on employment. The employment elasticity for the other firms' R&D in a plant's own area and industry is positive.

The results concerning the R&D spillovers' impacts on employment are mixed. The results obtained from manufacturing data hint that geographic distance is necessarily not very relevant while the results obtained from the data for all the industries deny this conclusion. All in all, we conclude that there is going on regional specialisation, wherefore the regional impact associated with R&D

investments are stronger than the respective impacts associated with total employment. There arises, however, employment effects also. Those areas which invest heavily in R&D seem also to gain in total employment.

6. SUMMARY AND CONCLUSIONS

In the first part of this empirical study the determination of R&D investments was analysed. In the second part R&D's influence on productivity was tested. Finally the interaction between the determination of employment and R&D activity was analysed.

The basic data set used in the analysis of plants' own R&D investments covers the periods 1987, 1989, 1991, 1993, 1995, 1997 and 1998. This data set includes those firms which have been included in R&D surveys of Statistics Finland. The explanatory plants' own and external R&D stock variables are lagged with two years. The basic data set includes only observations with positive R&D investments. This data set can also be extended with those firms that have announced their R&D investments are zero. The pools of external R&D stocks are based on the larger data set which includes approximates of practically all the relevant Finnish firms' R&D stocks.

It is not surprising that a plant's past R&D stock and its current turnover have a statistically significant positive impact on a firm's current investments. The main interest of this study is, however, on the impacts from other firms' past R&D stocks. It turned out that the other firms' past R&D stocks which are located in the same industry - either in the same area or in other areas, or in the same area but in other industries - positively contribute to current R&D investments. Only that part of external R&D which is located in other areas and in other industries has no positive impact on current R&D. In some regressions - for example when the firm-level data is used - this impact turned out to be negative.

When other firms' R&D is divided into only two pools, one which includes external R&D in the same sub-region and another which includes external R&D in other sub-regions, only the first mentioned pool has a positive influence on a plant's own R&D investment. A firm's own past R&D in other sites - whether in the same sub-region or in other sub-regions - has a positive impact on a plant's current R&D investments as well.

These results concerning the estimated elasticities for external R&D are quite robust. They do not change, even though those observations with zero current R&D are added to data. Neither does estimation of the simultaneous equation system with endogenous turnover through 2SLS change these basic results. The inclusion of industry dummies and sub-region dummies, however, changes the values of single elasticities and complicates the interpretation of results. Industrial proximity loses its relevance. But the geographical distance seems still to matter. The positive impact from other firms' R&D in the same sub-region and industry fades away, if one adds industry dummies or both industry and sub-region dummies in the model. The adding of these dummies changes also the estimates in the models where the other firms' R&D is sorted only into two pools. The R&D pool which is located near has either a positive or zero impact on a plant's R&D investments, while that part of other firms' R&D which is located in other areas has either zero or negative impact. So, there is no reason to reverse the conclusion according to which geographical proximity of external R&D encourages the plant's R&D investments. In the data which includes only those plants of which current R&D is observed in at least four periods out of a total of seven, the estimated coefficient of the random plant effect model still supports the previous results concerning the effects of short geographical and technological distance. Only the estimates of the fixed plant effect model - which takes into account only a variation inside the time interval - does not give any explanation for external R&D stocks. The within-plant results can, however, be interpreted to reflect rather short-run effects. Besides, the deep-going structural change of the Finnish industries in the years 1985-1998 do not support the idea of considering only within-plant variation.

According to the results, insofar as the spillover effect from the other firms' R&D in other areas and in the same industry is positive, it, however, weakens if the number of R&D active plants in this R&D stock pool increases. This dilution effect, discussed by Adams and Jaffe (1996), seems to describe those difficulties which firms face when they try to receive knowledge from many remote sources. Our results show that the dilution effect also concerns spillovers from a firm's other plants which are located in other sub-regions.

We also found that the dilution effect concerns small R&D investors rather than heavy R&D investors. This shows that small investors are more dependent on the geographical distance than heavy investors. That external R&D is in the same area or least in the same industry is a far more important factor in the determination of R&D investment for small investors than for heavy investors. The investment elasticity of a plant's own past R&D is much larger for heavy R&D investors - which are usually larger firms - than for small R&D investors.

The regressions which include the public authorities' R&D funding - loan or direct support - show that the R&D investment elasticity of public finance is about 0.2. This result corresponds to a situation in which the new publicly funded R&D investments do not crowd out privately funded R&D investments. If the public finance for R&D increases by one unit, the total R&D investments also increase by one unit. The estimation results for the model which includes a separate equation for public finance show that the other firms' R&D in the same industry has a positive impact on the amount of public finance received. The other industries' external R&D has an opposite impact. This negative net effect becomes stressed, if the other plants locate in other sub-regions also. This may indicate that a battle of limited public funding between the firms is going on. We also investigated whether the R&D investments of new plants form out differently than R&D investments in the old plants. It turns out that the R&D investment elasticity for public finance is larger for new plants than for old plants.

The data used in productivity analysis only concern manufacturing plants. The R&D data set - which is combined with the industrial statistics data of plants' value added and factors of production - specifies only the location - the municipality - of each firm's R&D. An industrial plant's own R&D stock is determined by the firm's R&D in the plant's location and on the other hand, on the basis of the plant's share of the firm's staff in the location concerned. The estimated elasticity for the firms' R&D in a certain location does not, however, change, even if the firm's R&D in a certain location is not divided between the plants in the municipality concerned.

The estimated productivity elasticity for a plant's own R&D turned out to be roughly 0.03. According to this, 10 percent rise in a plant's own R&D increases its productivity only by 0.3 percent. The exclusion of external R&D, however, increased this estimate to the level of 0.06, which is exactly the same as the estimate obtained by Lehtoranta (1998) with the Finnish data. Low, but statistically significant positive, elasticity was also obtained by Orlando (1999), who uses U.S. data and in whose estimation external R&D also was controlled.

According to the results, the estimated elasticity for other firms' past R&D which is located in the same sub-region and in the same industry is around 0.024. The estimated elasticity for other firms' R&D in other areas and in the same industry is about the same size. External R&D in the same sub-region but in other industries also positively contributes to productivity. Only the other firms' R&D which is located in other sub-regions and in other industries has no positive productivity impact. One unit increase in a plant's own R&D stock or in the other firms' R&D stock which is located in the same sub-region and in the same industry, leads, however, by far to a much larger increase in productivity than an increment in the other firms' R&D stocks which are located in other sub-regions or in other industries.

The external R&D from a firm's other plants in other sub-regions has a positive productivity impact as well, whereas the productivity elasticity for a firm's own R&D in other municipalities in the same sub-region is zero. In some regressions this elasticity is even negative, for which it is difficult to find any rational explanation. After the inclusion of industry dummies or both industry and sub-region dummies in the productivity model the elasticities for other firms' R&D in the same area remain positive. But spillover from other firms' R&D in the same industry and in the other regions loses its positive impact. All in all, both the geographical and technological proximity of external R&D also seems to matter in the formation of productivity.

We also analysed panel data which consist of only those plants which are observed during at least four periods. Even in the estimated random plant effect model (table 4.2) positive spillovers from other firms' R&D in the same area and in the same industry are emphasized. In the fixed plant effect model only this spillover has a positive impact. In this within-plant regression even the elasticity for a plant's own R&D becomes zero.

If the number of those units from which knowledge spillovers are received increases, given the amount of external R&D, the spillover effect on productivity weakens. This dilution effect discussed already by Adams and Jaffe (1996) is very strong as far the other firms' R&D in the same industry and in the other sub-regions, and also a firm's own R&D in other sub-regions, is concerned. Dilution - although much weaker - is associated with external R&D in own area but in other industries.

We also tested how a staff's education affects the productivity. According to the results, the increase in the share of those of the whole staff who have had education at the tertiary level has a remarkably positive impact on productivity.

Finally, we split the data into two pieces on the basis of firms' staff size. It turned out that the productivity of both small and large firms is favoured by the short geographical and industrial distance. We found that even the dilution effect concerns both small and large firms. It seems to be difficult for them to utilize many information sources simultaneously.

The impact of a plant's own and external R&D on the employment of manufacturing firms was also analysed. It turned out that only a plant's own R&D and the other firms' R&D in the same industry had a positive impact on total employment. This shows that the structural changes in the Finnish manufacturing arise not only from a plant's own R&D stock but also from the other firms' knowledge capital in the same industry.

We also found that changes in total employment do not depend on the geographical location of external R&D stocks so strongly as the determination of R&D investments or of productivity. This result can be explained by regional specialisation. A plant's own R&D and external R&D in the same sub-region strengthen local R&D activity, but do not necessarily improve the competitiveness of low-skill activities in the same area. On the contrary, in many sub-regions with scarce R&D the low cost of living, local infrastructure and supply of labour make the circumstances favourable to run assembly plants and other activities with not so strict requirements for the professional skills of the labour.

Regional specialisation is not, however, so dominant that the geographical location of R&D loses all of its influence on total employment. The sorting of other firms' R&D into only two pools revealed that geographical location of knowledge capital also matters in some extent in the determination of total employment. This is particularly so if a large which firm invests heavily in R&D expands in one location: it presumably restricts labour supply in other areas and thus negatively affects total employment in other areas.

The policy implications of this study are clear. According to the results, the policy intervention which increases R&D in one location in a specific industry, raises also productivity of other firms in the same area or in the same industry. As a consequence, the R&D activity of other firms in the same sub-region tend to grow. Possibly, total employment in the same area increases also, at least, the employment in the high-skill professions. This shows that there is room for regional policy in R&D field also.

Appendix A. Some estimation results

Table A1.
Period 1987-1998
Plant-level regression, data set A
2SLS

coefficient estimate (t-statistics in parentheses)

	R&D investments	***Turnover***
Intercept	2.306 (1.7)	14.987** (4.1)
Turnover, t	0.103** (10.5)	
Own R&D, t-2	0.641** (68.5	0.131** (10.5)
External R&D, own area, own industry, t-2	0.046** (5.9)	-0.002 (0.2)
External R&D, other areas, own industry, t-2	0.045** (5.8)	-0.009 (0.8)
External R&D, own area, other industries, t-2	0.049** (5.5)	-0.012 (0.9)
External R&D, other areas, other industries, t-2	0.138 (1.8)	-0.042 (0.4)
External R&D, own firm, other areas, t-2	0.112** (11.4)	0.134** (9.5)
External R&D, own firm, own area, t-2	0.145** (6.4)	0.036 (1.1)
Real GDP, t		-0.518* (2.4)
The size of staff, t-2		0.956** (68.7)
R^2	0.576	0.541
MSE	1.404	2.918
N	10010	10010

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Table A2.

Period 1987-1998
Dependent variable, R&D-investments - Plant-level regression, data set B
TOBIT

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*
Intercept	-0.292 (0.1)	0.798 (0.2)
Turnover, t	-0.007 (0.4)	-0.037* (2.0)
Own R&D, t-2	0.960** (35.2)	1.007** (36.7)
External R&D, own area, own industry, t-2	0.200** (8.7)	
External R&D, own area, t-2		0.050* (2.1)
External R&D, other areas, own industry, t-2	0.212** (9.4)	
External R&D, own area, other industries, t-2	-0.071** (2.7)	
External R&D, other areas, t-2		-0.250 (1.2)
External R&D, other areas, other industries, t-2	-0.121 (0.6)	
External R&D, own firm, other areas, t-2	-0.133** (4.4)	-0.123** (4.1)
External R&D, own firm, own area , t-2	-0.139 (1.9)	-0.157* (2.1)
N	21389	21389

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Table A3.

Dependent variable: R&D investments - Plant-level regression
Period 1987-1998
Panel data analysis

coefficient estimate (t-statistics in parentheses)

	Fixed effects	*Random effects*
Intercept		8.880** (3.7)
Turnover, t	0.212** (7.8)	0.236** (16.8)
Own R&D, t-2	0.070** (2.9)	0.511** (33.5)
External R&D, own area, own industry, t-2	-0.016 (0.6)	0.028* (2.0)
External R&D, other areas, own industry, t-2	-0.029 (0.8)	0.042** (2.7)
External R&D, own area, other industries, t-2	0.042 (1.1)	0.049** (2.9)
External R&D, other areas, other industries, t-2	-0.241 (1.0)	-0.114 (0.9)
External R&D, own firm, other areas, t-2	0.007 (0.2)	0.137** (8.3)
External R&D, own firm, own area, t-2	-0.145** (2.6)	0.102** (2.8)
R^2	0.835	0.663
MSE	0.661	0.801
N	2734	2734

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Table A4.

Dependent variable, fixed price value added - Plant-level regression
Period 1987-1998
Panel data analysis

coefficient estimate (t-statistics in parentheses)

	Fixed effects	*Random effects*
Intercept		8.278** (9.5)
Time trend	0.067** (17.7)	0.064** (20.8)
Labour input, t	0.763** (43.8)	0.746** (63.5)
Capital input, t	0.100** (7.4)	0.188** (21.8)
Own R&D, t-2	0.003 (0.5)	0.016** (2.6)
External R&D, own area, own industry, t-2	0.018** (2.6)	0.024** (3.9)
External R&D, other areas, own industry, t-2	0.005 (0.9)	0.011* (2.3)
External R&D, own area, other industries, t-2	-0.009 (1.0)	-0.005 (0.8)
External R&D, other areas, other industries, t-2	-0.027** (3.7)	-0.231** (4.4)
External R&D, own firm, other areas, t-2	0.006 (1.1)	0.016** (3.3)
External R&D, own firm, own area, t-2	-0.019 (1.2)	-0.008 (0.6)
R^2	0.927	0.806
MSE	0.189	0.191
N	6985	6985

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Table A5.

Period 1987-1998

Dependent variable, number of employees - Plant-level regression.

Based on data set B, OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*
Intercept	-4.780* (3.5)	0.651 (0.3)	-5.605** (4.2)	-3.316 (1.8)
Number of employees, t-2	0.896** (174.0)	0.889** (171.6)	0.897** (174.4)	0.896** (173.5)
Own R&D, t-2	0.057** (10.4)	0.051** (9.4)	0.056** (10.4)	0.057** (10.4)
External R&D, own area, own industry, t-2	-0.005 (1.2)	0.030** (5.6)		
Number of other units, own area , own industry, t-2		-0.129** (9.6)		
External R&D, own area, t-2			-0.001 (0.2)	0.023** (2.6)
Number of other units, own area t-2				-0.045** (3.1)
External R&D, other areas, own industry, t-2	-0.005 (1.1)	0.016** (2.7)		
Number of other units, other areas, own industry, t-2		-0.035** (3.2)		
External R&D, own area, other industries, t-2	-0.005 (1.1)	0.010 (1.1)		
Number of other units, own area , other industries, t-2		-0.024 (1.6)		
External R&D, other areas, t-2			-0.092* (2.5)	-0.188** (3.6)
Number of other units, other areas, t-2				0.118 (1.8)
External R&D, other areas, other industries, t-2	-0.133** (3.4)	-0.375** (6.8)		
Number of other units, other areas, other industries, t-2		0.255** (4.0)		
External R&D, own firm, other areas, t-2	0.004 (0.7)	-0.009 (1.3)	-0.004 (0.7)	-0.002 (0.3)
Number of other units, own firm, other areas, t-2		0.063* (2.1)		0.040 (1.4)
External R&D, own firm, own area, t-2	0.009 (0.6)	0.000 (0.0)	0.009 (0.6)	0.009 (0.6)
Number of other units, own firm, own area, t-2		0.113 (0.3)		0.200 (0.6)
Real value of GDP	0.720** (8.7)	0.470** (3.8)	0.737** (8.9)	0.619** (5.0)
R^2	0.673	0.676	0.673	0.673
MSE	0.823	0.815	0.823	0.822
N	21163	21163	21163	21163

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.

* Indicates 5% level of significance.

Table A6.

Period 1987-1998

Dependent variable, number of employees - fixed industry and region effect regressions.
Based on data set D, 104 industry dummies & 87 sub-region dummies, OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*
Intercept	-3.998** (5.8)	4.408** (3.2)	-4.321** (6.4)	4.111** (2.9)
Number of employees, t-2	0.989** (297.0)	0.989** (297.1)	0.989** (297.4)	0.989** (297.6)
Firm's own R&D, t-2	-0.002 (0.5)	-0.002 (0.6)	0.006 (1.8)	-0.002 (0.7)
Number of plants which share past R&D stock	-0.013 (1.5)	-0.010 (1.1)	-0.013 (1.5)	-0.010 (1.1)
External R&D, own area, own industry, t-2	0.006* (2.0)	0.006 (1.7)		
Number of other units, own area , own industry, t-2		-0.003 (0.2)		
External R&D, own area, t-2			-0.007 (1.4)	-0.010 (1.7)
Number of other units, own area t-2				0.012 (0.7)
External R&D, other areas, own industry, t-2	0.007 (1.5)	-0.000 (0.0)		
Number of other units, other areas, own industry, t-2		0.031* (2.2)		
External R&D, own area, other industries, t-2	-0.007 (1.5)	-0.011 (1.8)		
Number of other units, own area , other industries, t-2		0.010 (0.5)		
External R&D, other areas, t-2			-0.030 (1.3)	-0.133** (4.8)
Number of other units, other areas, t-2				0.221** (6.0)
External R&D, other areas, other industries, t-2	-0.046* (2.0)	-0.147** (5.2)		
Number of other units, other areas, other industries, t-2		0.201** (5.3)		
External R&D, own firm, other areas, t-2	-0.002 (0.5)	-0.002 (0.5)	-0.004 (1.4)	-0.003 (0.9)
Number of other units, own firm, other areas, t-2		-0.006 (0.3)		-0.012 (0.7)
External R&D, own firm, own area, t-2	-0.001 (0.1)	0.001 (0.2)	-0.002 (0.2)	0.000 (0.1)
Number of other units, own firm, own area, t-2		-0.488** (2.7)		-0.497** (2.8)
Real value of GDP	0.582** (11.0)	-0.033 (0.3)	0.586** (11.1)	-0.041 (0.4)
R^2	0.924	0.925	0.924	0.924
MSE	0.134	0.133	0.134	0.133
N	10955	10955	10955	10955

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Table A7.

Period 1987-1998
Dependent variable, number of employees - fixed industry and region effect regressions.
Based on data set B, 195 industry dummies & 88 sub-region dummies, OLS

coefficient estimate (t-statistics in parentheses)

	(1)	*(2)*	*(3)*	*(4)*
Intercept	-4.383 (1.7)	-3.480 (1.1)	-3.804 (1.4)	-3.260 (1.0)
Number of employees, t-2	0.833** (152.4)	0.832** (151.6)	0.834** (152.4)	0.833** (152.1)
Own R&D, t-2	0.065** (11.6)	0.065** (11.8)	0.066** (11.9)	0.066 (12.0)
External R&D, own area, own industry, t-2	0.010* (2.3)	0.017** (2.9)		
Number of other units, own area , own industry, t-2		-0.034* (2.2)		
External R&D, own area, t-2			-0.019 (1.4)	0.009 (0.5)
Number of other units, own area t-2				-0.145** (3.5)
External R&D, other areas, own industry, t-2	-0.010 (0.9)	0.011 (0.9)		
Number of other units, other areas, own industry, t-2		-0.134** (3.6)		
External R&D, own area, other industries, t-2	-0.032* (2.3)	-0.006 (0.3)		
Number of other units, own area , other industries, t-2		-0.124** (3.1)		
External R&D, other areas, t-2			-0.208* (2.0)	-0.276* (2.5)
Number of other units, other areas, t-2				0.342** (3.6)
External R&D, other areas, other industries, t-2	-0.178 (1.8)	-0.316** (2.8)		
Number of other units, other areas, other industries, t-2		0.453** (4.6)		
External R&D, own firm, other areas, t-2	-0.007 (1.2)	-0.006 (0.8)	-0.009 (1.4)	-0.008 (1.1)
Number of other units, own firm, other areas, t-2		-0.008 (0.2)		0.004 (0.1)
External R&D, own firm, own area, t-2	0.015 (1.0)	0.015 (1.0)	0.014 (1.0)	0.014 (1.0)
Number of other units, own firm, own area, t-2		-0.123 (0.4)		-0.109 (0.3)
Real value of GDP	0.722** (7.5)	0.562** (4.1)	0.725** (7.6)	0.566** (4.1)
R^2	0.695	0.695	0.695	0.695
MSE	0.777	0.777	0.778	0.778
N	21163	21163	21163	21163

** Indicates that the estimates parameter is significantly different from zero at the 1% level of significance.
* Indicates 5% level of significance.

Apendix B. Data descriptions

Data set A,
N=10010

Variable	*Mean*	*Min*	*Max*
R&D investments	6.00	0.01	13.90
Turnover	9.30	0.17	16.65
Own R&D	7.51	0.00	14.58
R&D, external, own area, own industry	9.56	1.54	14.83
Number of other units, own area, own industry	1.86	0.69	4.74
R&D, external, other areas, own industry	11.75	3.45	15.44
Number of other units, other areas, own industry	3.49	0.69	4.74
R&D, external, own area, other industries	13.24	4.06	16.42
Number of other units, own area, other industries	4.45	0.69	6.79
R&D, external, other areas, other industries	16.87	16.19	17.18
Number of other units, other areas, other industries	7.81	7.35	8.10
R&D, external, own area	13.28	4.06	16.42
Number of other units, own area	4.48	0.69	6.79
R&D, external, other areas	16.88	16.21	17.18
Number of other units, other areas	7.82	7.39	8.10
R&D, external, own firm, other areas	9.09	1.11	15.36
Number of other units, own firm, other areas	1.22	0.69	4.74
R&D, external, own firm, own area	8.28	0.17	14.41
Number of other units, own firm, own area	0.73	0.69	1.39
Research in universities	7.89	1.36	9.28
Gdp	13.27	13.17	13.39
Staff size	3.66	0.03	9.86

Data set B,
N=21389

Variable	*Mean*	*Min*	*Max*
Turnover, t	9.05	0.18	16.65
Own R&D, t-2	7.29	0.00	14.58
R&D, external, own area, own industry, t-2	9.27	0.17	14.83
Number of other units, own area, own industry, t-2	1.81	0.69	4.74
R&D, external, other areas, own industry , t-2	11.51	2.25	15.44
Number of other units, other areas, own industry, t-2	3.43	0.69	5.67
R&D, external, own area, other industries, t-2	13.16	4.06	16.42
Number of other units, own area, other industries, t-2	4.39	0.69	6.79
R&D, external, other areas, other industries, t-2	16.88	16.19	17.18
Number of other units, other areas, other industries, t-2	7.82	7.35	8.10
R&D, external, own area, t-2	13.19	4.06	16.42
Number of other units, own area, t-2	4.42	0.69	6.79
R&D, external, other areas, t-2	16.90	16.21	17.18
Number of other units, other areas, t-2	7.84	7.39	8.10
R&D, external, own firm, other areas, t-2	9.14	0.55	15.36
Number of other units, own firm, other areas, t-2	1.14	0.69	3.04
R&D, external, own firm, own area, t-2	8.15	0.17	14.41
Number of other units, own firm, own area, t-2	0.72	0.69	1.39

Data set C,
N=7714

Variable	Mean	Min	Max
R&D investments	5.98	0.01	13.90
Turnover, t	9.28	0.18	16.65
Own R&D, t-2	7.50	0.01	14.58
R&D, external, own area, own industry, t-2	9.62	1.54	14.83
R&D, external, other areas, own industry, t-2	11.80	3.45	15.44
R&D, external, own area, other industries, t-2	13.41	6.07	16.42
R&D, external, other areas, other industries, t-2	16.87	16.19	17.18
R&D, external, own area, t-2	13.45	6.07	16.42
R&D, external, other areas, t-2	16.89	16.21	17.18
R&D, external, own firm, other areas, t-2	8.92	1.11	15.36
R&D, external, own firm, own area, t-2	8.20	0.17	14.41
Public finance, t	4.80	0.00	9.94
The share of those of the research staff of having had education at the tertiary level, t	0.574	0.00	1.00
Real interest rate, t	5.73	3.4	7.8

Data set D,
N=11527

Variable	*Mean*	*Min*	*Max*
Production volume, t	9.85	0.087	16.40
Labour input, hours, t	4.58	0.00	8.93
Staff size, t	4.09	0.00	8.41
Capital input, t	2.03	-0.264	15.32
Own R&D, t-2	7.67	0.00	14.58
R&D, external, own area, own industry, t-2	8.81	0.88	14.66
Number of other units, own area, own industry, t-2	1.16	0.69	3.00
R&D, external, other areas, own industry, t-2	11.07	1.83	15.31
Number of other units, other areas, own industry, t-2	2.63	0.69	4.49
R&D, external, own area, other industries, t-2	11.87	2.65	16.15
Number of other units, own area, other industries, t-2	3.21	0.69	6.36
R&D, external, other areas, other industries, t-2	16.51	15.49	16.81
Number of other units, other areas, other industries, t-2	7.06	6.50	7.54
R&D, external, own area, t-2	11.92	2.65	16.15
Number of other units, own area, t-2	3.23	0.69	6.36
R&D, external, other areas, t-2	16.52	15.52	16.81
Number of other units, other areas, t-2	7.08	6.56	7.54
R&D, external, own firm, other areas, t-2	9.77	1.11	15.22
Number of other units, own firm, other areas, t-2	1.11	0.69	2.71
R&D, external, own firm, own area, t-2	9.27	3.45	14.58
Number of other units, own firm, own area, t-2	0.72	0.69	1.10

Data set E,
N=8274

Variable	*Mean*	*Min*	*Max*
Turnover, t	9.42	0.43	17.54
Own R&D, t-2	7.69	1.62	15.37
R&D, external, own area, own industry, t-2	9.97	0.87	15.26
R&D, external, Other areas, own industry, t-2	11.85	1.36	15.45
R&D, external, Own area, other industries, t-2	14.06	6.14	17.06
R&D, external, Other areas, other industries, t-2	17.09	15.88	17.48
R&D, external, own area, t-2	14.10	6.14	17.06
R&D, external, other areas, t-2	17.11	15.88	17.48
The number of own units, t-2	0.81	0.69	3.04
Research in universities, t-2	9.32	1.98	11.35

Appendix C. Theory on profits and R&D investments

In this section we analyze the determination of R&D investments. Following Cohen and Klepper (1996) we stress that through process or product innovations the firm can only increase its profits temporarily. Product innovations can be viewed as creating a new product variant with improved quality which in the form of transient monopoly power gives a firm an opportunity to temporarily enlarge a price-cost margin. As soon as its competitors manage to imitate the innovator, this advantage is eliminated.

Let us consider a single firm, firm A. The other firms are denoted by subscript B. Firm A's R&D capital is denoted by R_A, and, respectively, the other firms' R&D capital is denoted by R_B. For simplicity, we do not make any difference between R&D activity directed to product innovations and process innovations.

R&D stock R_A increases firm A's profits in two different ways. In the first place, promoting process innovations, it decreases A's unit costs and raises A's productivity. When product innovations are generated, R_A increases profits by widening the price-cost margin. The other firms' R&D in the form of R_B behaves as a spillover which affects A's profits similarly with R_A. But R_B also affects A's profits indirectly through the market. Insofar as the other firms compete with firm A, their own R&D investments help them to strengthen their market position - through quality improvements and new superior products - at the expense of firm A. Besides, through process innovations the other firms can lower the market price and narrow firm A's price-cost margin.

We assume that firm A's price level P_A has the equation

(c1) $P_A = a(R_A,R_B)$.

Notation $a_1 \equiv \partial a(R_A,R_B)/\partial R_A$ and $a_2 \equiv \partial a(R_A,R_B)/\partial R_B$ is followed. It is clear that $a_1 > 0$, whereas the sign of a_2 is ambiguous. If the spillover effect dominates $a_2 > 0$, whereas, if the competition effect is dominant, $a_2 < 0$. How an increase in R_B affects

R_A highly depend on cross-derivative a_{12}. Insofar as only the competition effect is concerned, $a_{12} < 0$. The more competitors invest in R&D, the less firm A gains market power and the weaker are the opportunities to raise prices. Besides, when A and B are competitors, R_B as a spillover is rather R_A's substitute than its complement. The other firm's R&D stock can also complement firm A's own R&D efforts in improving product quality and in inventing new products, even if firm A competes with other firms. In that case $a_{12} > 0$. It is also assumed that $a_{11} < 0$.

Firm A's costs C are determined by

(c2) $C = G(Q_A, R_A, R_B, Z_A) + c_A R_A$

where

Q_A = product volume
Z_A = the prices of other inputs (ordinary labour, physical capital and materials).
c_A = factor price associated with maintaining firm A's R&D-stock R_A.

The costs accrued from the maintenance of the ability to absorb knowledge included in R_B are part of G as well.

In (c2) $G_1 > 0$, $G_2 < 0$, $G_3 \leq 0$, and $G_4 > 0$. So the costs increase in Q_A and in the price vector Z_A. The unit costs decrease (and productivity increases) in R_A if

(c3) $\partial G/\partial R_A + c_A < 0$.

We assume that inequality (c3) is valid. It must be noticed that R_B affects costs only through spillovers, so this effect cannot be positive. For this same reason an increase in R_B unambiguously increases A's productivity. In cost function R_A and R_B can also act either as complements or as substitutes. If they are complements, G_{23} is negative. Because the competition effect is absent in cost formation, it is more likely that $G_{23} < 0$ than that $a_{12} > 0$. I also assume that $G_{22} < 0$.

If the markets for R&D resources are large and developed, price c_A can be considered as given. Narrow markets for R&D-experts may, however, make c_A dependent on $R_A + R_B$ so that $\partial c_A(R_A + R_B)/\partial(R_A+R_B) > 0$. Of course, the imperfect financial markets can also make R&D-costs increase with $R_A + R_B$ owing to rising financing costs.

The firm A's profits have the equation

(c4) $\Pi_A = a(R_A,R_B)Q_A - G(Q_A,R_A, R_B,Z_A) - c_A R_A$.

Let us assume that c_A is given. According to the first order conditions of maximization

(c5) $$\frac{\partial \Pi_A}{\partial R_A} = a_1 Q_A - G_2 - c_A = 0.$$

Considering Q_A also as given it is obtained from (c5)

(c6) $$dR_A/dR_B = -\frac{a_{12}Q_A - G_{23}}{a_{11}Q_A - G_{22}}.$$

In (c6) the denominator is negative (which guarantees that the second order conditions are valid). The numerator is positive if R_A and R_B are complementary to each other both in price and cost equation. Then R_B increases R_A so that $dR_A/dR_B > 0$. If the other firms compete with A and if the spillovers from their R&D stock is a substitute for R_A, an increase in R_B, however, lowers firm A's R&D investments.

The impact of R_B on A's profits is obtained by differentiating Π_A with respect to R_B. The respective expression is

$$\partial \Pi_A/\partial R_B = a_2 Q_A - G_3 R_A.$$

Again the impact considered can be either positive or negative. But only if the competition effect dominates can this impact be negative. If indirect effects which come out through lowering market prices are weak or non-existent, $\partial\Pi_A/\partial R_B$ is positive, even if spillovers from R_B substitute the services released by R_A. All in all, it is possible that the other firms' R&D investments decrease firm A's R&D investments but increase A's profits. The possible negative effects both on R_A and on Π_A are strengthened, if factor price c_A is related inversely to $R_A + R_B$.

Insofar as the public R&D subsidies decrease marginal costs c_A, their effect on R_A is of the magnitude

$$\text{(c7)} \qquad dR_A/(-dc_A) = -\frac{R_A}{a_{11}Q_A - G_{22}}$$

and thus unambiguously positive. How limited the availability of finance and narrowness of the R&D labour market affect R&D investments is analysed more deeply in the later stages of this study. In financing R&D investments, the availability of finance creates obstacles for investments. More specifically, it is possible (see Hall, 1992) that there is a moral hazard problem in transferring information about a risky project from an entrepreneur (firm) to investors (owners). Besides, if the owners restrict the increase of leverage, the only alternative which is left is to force a firm to external capital markets in order to finance the project. The costs of financing in external capital markets is however more expensive than from other sources, so that public financial support could be effective in increasing R&D investments.

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