No. 184 | November 1996 | Discussion Papers

Statistics Norway
Research Department

Discussion Papers

Tor Jakob Klette and Frode Johansen

Accumulation of R&D Capital and Dynamic Firm Performance: A Not-so-fixed Effect Model

Statistics Norway
Statistisk sentralbyrå

Tor Jakob Klette and Frode Johansen

Accumulation of R&D Capital and Dynamic Firm Performance: A Not-so-fixed Effect Model

Abstract:
Considering the observed patterns of R&D investment, we argue that a model which allows for a positive feedback from already acquired knowledge to the productiveness of current research, fits the empirical evidence better than the standard model that treats knowledge accumulation symmetrically to the accumulation of physical capital. We present an econometric framework consistent with a positive feedback in the accumulation of R&D capital. The empirical model is econometrically simple and less data-demanding than the standard framework. Our estimates show a significant positive effect of R&D on performance and a positive feedback effect from the stock of knowledge capital. We calculate the depreciation rate and the rate of return to knowledge capital for our alternative framework, and compare our estimated rate of return to results obtained within the standard framework.

Keywords: Productivity, R&D, Knowledge Accumulation, Panel Data.

JEL classification: D24, O30.

Acknowledgement: We have benefited from comments from B.H. Hall, S. Machin, J. Mairesse, Ø.A. Nilsen and participants at the "Economics and econometrics of innovation" conference in Strasbourg, June 3-5, 1996, the "CAED'96" conference in Helsinki, June 17-19, 1996, and the "First Bergamo workshop on applied economics" in Bergamo, October 11-12, 1996. The project has received financial support from the Norwegian Research Council (Nærings-LOS).

Address: Tor Jakob Klette, Statistics Norway, Research Department,
P.O.Box 8131 Dep., N-0033 Oslo, Norway. E-mail: tjk@ssb.no

1 Introduction

Over the last 10-15 years, we have seen an outburst of econometric research on R&D investment and productivity; see Griliches (1995) for a recent survey of the many insights that have emerged from this line of research. Much of this research follows the framework outlined in Griliches (1979). In this paper we argue that this econometric framework should be modified and extended in various ways. In particular, considering the empirical evidence on the patterns of R&D investment, we argue that a model which allows for a positive feedback from already acquired knowledge to the productiveness of current research fits the empirical evidence better than the standard model that treats knowledge accumulation symmetrically to the accumulation of physical capital. Positive feedbacks in knowledge accumulation have recently been considered in the literature on macroeconomic growth by Romer (1990), Milgrom, Qian and Roberts (1991), and Jones (1995). Their argument is that this feedback mechanism can explain the persistent differences in productivity between countries or industries, and why some industries or countries suddenly gain momentum and go through phases of high growth.

Our analysis is concerned with a related phenomenon at the micro level; how can we rationalize that some firms are persistently, often for a long period, more productive than other firms, as shown e.g. by Bailey, Hulten and Campbell (1992). Similarly, why do some firms persistently carry out considerable R&D, while other firms in the same industry never report any R&D investments? Empirically, it is widely observed that there are large differences in R&D effort across firms within narrowly defined industries, and that these differences in R&D effort are persistent over time. Nelson (1988) has pointed out that this co-existence of innovators and imitators - as he calls them - is a puzzle for the standard framework for productivity analysis at the micro level. We argue that positive feedbacks in knowledge accumulation can be one explanation for the persistency of performance differences at the micro level, parallel to the cited arguments presented in the macro growth literature. The co-existence of innovators and imitators can within our framework be considered a consequence of the stochastic nature of knowledge production in combination with a positive feedback from past R&D success to the productiveness of current R&D.

We present a simple, alternative specification for the accumulation of R&D capital that differs from the standard specification in the R&D productivity literature. After an analysis of R&D investment for both the standard and our alternative specification, we show that our alternative specification better fits the empirical patterns with persistent differences in R&D activity between firms in the same industry. The second main part of this paper presents an empirical analysis of R&D, productivity and performance that uses our alternative specification for R&D investment and knowledge accumulation. In this empirical analysis we also alter and augment the standard framework as presented in Griliches (1979, 1995), in other ways, by explicitly incorporating the demand side and both process and product innovations. We have estimated this empirical model on a new data set that links R&D investment at the line-of-business level (within each firm) to plant level data on productivity. The results show that R&D investment is a significant determinant of dynamic performance and that the appropriable part of R&D capital depreciates quite rapidly.

The analysis presented here is in several ways an extension of the analysis presented in Klette (1996): First, the present paper presents a formal analysis of optimal R&D investment when the accumulation process allows for the feedback mechanism in our alternative specification. Second, we present an empirical analysis of R&D investment to illustrate the empirical importance of our respecification. Third, the formal analysis of optimal R&D investment leads us to a formula for calculating the private rate of return to R&D investment. Finally, the empirical analysis in section 4 is carried out on a new data set that links R&D data at the line of business level to plant level data for the period 1980-92 (while Klette, 1996, used only a single cross section of R&D data for 1989). This new, larger data set allows us to explore a number of specification issues and formal econometric tests that were not possible with the limited data set used in Klette (1996).

The rest of our paper is organized as follows: In section 2, we examine patterns of R&D investments. After discussing R&D investment in the standard model of knowledge accumulation, we present a dynamic programming analysis of optimal R&D investment for our alternative specification of the accumulation process. This analysis is then confronted with empirical patterns of R&D investment in the second half of section 2. Having concluded that our alternative specification of knowledge accumulation fits the empirical data better, we proceed to the empirical analysis of R&D, productivity and performance in sections 3 and 4, based on our alternative specification of knowledge accumulation. For comparison, we start in section 3 with a standard analysis of R&D and productivity, following Griliches (1979, 1995) and Hall and Mairesse (1995). Section 4 contains the main part of our analysis of R&D and performance, where we spell out the empirical framework and present the econometric results. We add some final comments in section 5.

2 Investment in R&D capital and performance

2.1 Persistent cross sectional differences in R&D investment: Theory

The standard framework treats the accumulation of knowledge capital in the same way as that of physical capital, using the "perpetual inventory" process as a common framework. Formally,

$$K_{it+1} = K_{it}(1-\delta) + R_{it} \quad , \tag{1}$$

where K_{it} and R_{it} represent knowledge capital and R&D investment for firm i in year t.

We will argue that the standard framework contradicts the widely observed pattern that the same firms tend to persistently carry out above (or below) average amounts of R&D, say, relative to their sales. This persistence in the differences in R&D intensities between firms within the same industry is hard to rationalize on the basis of a knowledge accumulation process as specified in equation (1).

To clarify our point, assume a Cobb-Douglas production function, $Q_{it} = \Phi_{it} X_{it}^{\alpha^X} K_{it}^{\alpha^K}$, where Q_{it} is output, Φ_{it} a productivity term, and X_{it} inputs. A firm's rate of return to knowledge capital can then be calculated as $\alpha^K \frac{Q_{it}}{K_{it}}$.

This expression implies that if we consider two firms which differ only in their knowledge capital stocks at the beginning of a period, the firm with the lowest R&D capital stock should have the highest return on an increase in its capital stock. Since equation (1) implies that a unit of R&D investment generates a unit of R&D capital, one should expect highest investment by the firm with the smallest R&D capital stock. Note that the argument above is valid even if firms differ in terms of productivity, Φ_{it}.

A second weakness of the model is its treatment of other factors that could account for persistent differences in the level of the R&D activity. Such factors are often captured by so-called fixed effects in empirical research on firm level data. While the presence of fixed effects can make the model consistent with the observed cross sectional differences in R&D activity, they are not very satisfactory. First, econometric studies of R&D and productivity based on models with fixed effects often give weak, if significant results, and the estimates are often not robust; see the survey by Mairesse and Sassenou (1991). Second, while our model suggests a mechanism generating persistent differences in R&D investment, models with fixed effects only account for such differences without offering any explanation how such differences have been generated.

2.1.1 An alternative specification of knowledge accumulation

A possible explanation for the observation that a high return on knowledge capital does not lead to R&D investments is that the relationship between R&D investment and knowledge capital is more complex than in equation (1). There is an alternative to the perpetual inventory model of capital accumulation that suggests that old capital and new investment are *complementary* inputs in the production of new capital. This view seems particularly relevant for the accumulation of knowledge capital, as noticed by Griliches (1979), Hall and Hayashi (1989), Romer

(1990), Jones (1995) and Klette (1996). The basic idea is that greater initial knowledge will tend to increase the amount of knowledge obtained from a given amount of R&D. The specific model of capital accumulation we will consider here was originally presented by Uzawa (1969), who attributed the idea to Penrose (1959)[1].

Formally, we will assume that knowledge capital can be accumulated according to the equation[2]

$$K_{t+1} = K_t^{(\rho-\nu)} R_t^{\nu}. \tag{2}$$

The firm maximizes its net present value; $V(K_0)$, given its initial knowledge capital stock (K_0):

$$V(K_0) = \max_{\{R_t\}} \sum_{t=1}^{\infty} \beta^t (\pi_t(K_t) - w_t R_t), \tag{3}$$

subject to the accumulation equation (2). β is the discount factor, $\pi_t(K_t)$ is the profit function conditional on the knowledge capital stock, excluding R&D investment cost, while w_t is the unit cost of R&D investment. For convenience, we have not included other kinds of capital or uncertainty in the model. This can be done without changing the argument; it only involves more notation.

As shown for instance by Stokey and Lucas (1989, ch. 4), under mild regularity conditions the value function satisfies the Bellman-equation:

$$V(K_t) = \max_{R_t}[\ \pi_t(K_t) - w_t R_t + \beta V(\ K_{t+1}\ )\ ], \tag{4}$$

where K_{t+1} is a function of K_t and R_t as specified in (2). Assuming strict concavity of the short run profit function (in K_t), the optimal R&D investment must satisfy the first-order condition:

$$-w_{t-1} + \beta V'(K_t) \frac{\partial K_t}{\partial R_{t-1}} = 0 \tag{5}$$

Furthermore, as the Bellman equation (4) is supposed to hold for all initial knowledge capital stocks, we have that

$$V'(K_t) = \pi'(K_t) + \beta V'(K_{t+1}) \frac{\partial K_{t+1}}{\partial K_t}. \tag{6}$$

Eliminating the V's from this equation by equation (5), we find that

$$\frac{1}{\beta} w_{t-1} \left(\frac{\partial K_t}{\partial R_{t-1}} \right)^{-1} = \pi'(K_t) + w_t \left(\frac{\partial K_{t+1}}{\partial R_t} \right)^{-1} \frac{\partial K_{t+1}}{\partial K_t} \tag{7}$$

Or, using (2), and rearranging some terms:

$$w_{t-1} R_{t-1} = \beta[\nu\, \pi'(K_t) K_t + (\rho - \nu) w_t R_t] \tag{8}$$

[1]Penrose and Uzawa put the model forward as a model of physical capital accumulation. Their argument was that physical capital investment requires organizational skills or capital as a complementary input, and organizational capital involves an accumulation process where past knowledge gives a positive feedbacks to the acquisition of new knowledge.

[2]It can be shown that the log-linear specification is not essential for the argument below.

Below, we show that a common specification of the profit function implies that $\pi'(K_t) = \gamma\, S_t/K_t$, where S_t is sales. In this case

$$\frac{w_{t-1}R_{t-1}}{S_t} = \beta\left[\nu\gamma + (\rho - \nu)\frac{w_t R_t}{S_t}\right]. \tag{9}$$

Cross-sectional differences in sales are highly autocorrelated i.e. $S_{t-1} \simeq S_t$. Hence, equation (9) predicts that differences in the R&D intensity between different firms should be highly correlated over time. In section 2.2, we will provide empirical support for this prediction.

To summarize, the multiplicative model of knowledge accumulation considered in this section rationalizes why the same firms persistently invest above (or below) average in R&D. The main reason identified here is the intertemporal complementarity in the R&D activity; past experience makes current R&D effort more productive. We have formally showed that this mechanism leads to a pattern of persistent differences in R&D intensities between firms, a well known empirical pattern which is hard to rationalize in the standard framework.

A final point should be mentioned. Adding covex in R&D to a model based on the perpetual inventory specification, could give an alternative interpretation of the observed serial correlation in R&D. However, we find it hard to understand why there are adjustment costs associated with a stable path of R&D investment and why these costs should be convex[3]. Also, given the relatively poor performance of Euler equations for R&D investments we find it attractive to examine alternative models.

2.2 Persistent cross sectional differences in R&D investment: Empirical evidence

This section provides empirical evidence on two features of R&D investment behavior which motivate the alternative model of knowledge accumulation: The heterogeneity and persistence in R&D intensities.

The empirical analysis is based on two primary data sources; the annual manufacturing census carried out by Statistics Norway and the R&D survey carried out by the Norwegian Research Council for Science and Technology (NTNF) until 1989 and by Statistics Norway from 1991. Our analysis covers the period 1980-92 and the following industries: "Chemicals", "Mineral products", "Basic metals" and "Metal products". These industries account for almost all R&D in Norwegian manufacturing. Further details on our data sources and samples are given in appendix A.

One of the advantages with the Norwegian R&D data is that R&D is reported at the *line of business level within each firm.* The production data are reported at the plant level, and they

[3]Adjustment costs associated with *changes* in R&D investment seem more plausible.

have been aggregated to the line-of-business level for the analysis in this section where we will examine cross sectional and longitudinal patterns in R&D intensities.

Figure 1 shows the distribution of R&D intensities with the line-of-business within each firms as the unit of observation. The figure presents the distribution of R&D intensities for each 3-digit industry and for the complete sample. We see from figure 1 that even within relatively narrowly defined industries there is a large amount of heterogeneity in R&D intensities. As Cohen and Klepper (1992) found, the distribution of R&D intensities is highly skewed in most industries, with a large fraction of the line-of-businesses reporting little or no R&D[4]. There is a censoring problem for line-of-businesses that are not reporting R&D. Most of these firms are probably accumulating new knowledge, but often by other means than formal R&D. The firms without R&D create well-known problems for empirical analysis that we will return to in section 4.

Cohen and Klepper examined only a single cross section of firms. With a set of panel data, we can push the issue a step further. Table 1 shows that not only is the distribution of R&D intensities highly skewed; it is also the same firms that invest heavily in R&D year after year. Table 1 shows transition probabilities for categories of R&D intensities. The table shows that 90% of the plants which have no R&D in a given year, have no R&D two years later. More than 60% of the plants in the highest quartile of R&D plants are in this quartile two years later. This persistence in R&D intensities indicates that there are persistent differences in R&D investment opportunities across firms.

Another way to illustrate the same point is presented in figure 2; the figure shows ranks of R&D intensities in year t vs. year $t+2$, ... , $t+8$. The figure shows a positive autocorrelation pattern. For comparison, the analysis is repeated for physical capital investment intensities in figure 3. The autocorrelation pattern for fixed investment (intensities) is weak. A comparison of figures 2 and 3 shows that R&D investments are much more persistent than for physical capital investments. High persistence in the short run could also be explained by adjustment costs, as mentioned above. However, the fact that the degree of persistence is quite high over a large number of years for R&D suggests that standard convex adjustment costs are an inadequate explanation. The positive feedback effect incorporated in the model presented in section 2.1 is consistent with persistent differences in investment opportunities in R&D, cf. equation (9).

We noticed in section 2 that the positive feedback effect incorporated in the multiplicative model for capital accumulation was originally put forward as a model for physical capital investments by Penrose (1959), Uzawa (1969); see also Shen (1970) who examined the empirical performance of the model. Our comparison of the patterns in figures 2 and 3 suggests that the

[4]See also Bound et al. (1984), Klette (1994b), and Pakes and Schankerman (1984).

positive feedback effect is much weaker in the accumulation of physical capital as compared to the case with R&D capital.

3 R&D and productivity: a standard analysis

Before we present our main analysis, it is useful to present an econometric analysis of productivity and R&D based on the standard framework. By estimating some of the traditional models in the literature we want to illustrate two points: In the cross section, there is a positive relationship between R&D and productivity, while this relationship is quite weak in the longitudinal dimension.

In columns 1-8 of table 2 we estimate the output elasticity of the R&D capital stock, following the standard approach in the literature[5]. The R&D capital stock is constructed by accumulating R&D investments according to equation (1) from an initial year. We assume a 15% depreciation rate for R&D and a R&D expenditure growth rate of 10% prior to the first observation for each line of business (firm)[6]. The first six columns of the table give results for a log-linear (i.e. Cobb-Douglas) technology for two different measures of output, i.e. from estimating

$$y_{it} = \alpha + X_{it}\beta + \gamma k_{it} + e_{it},$$

where y_{it} is log output (either gross output or value added), X_{it} is a vector representing (log) capital and labor, as well as materials if output is measured by gross output. k_{it} is log of the R&D capital stock and γ is the parameter of primary interest.

Column (1) shows that R&D has a significant effect on value added. Including time and industry dummies as in column (2) gives almost identical results. A positive cross sectional relationship between productivity and the stock of knowledge capital has been found in a number other studies; see the surveys by Mairesse and Sassenou (1991) and Griliches (1988, 1995). In column (3), we see that when fixed effects are included, the relationship between R&D and productivity becomes weaker. This result is not surprising given the high persistence in R&D investments discussed above, and is well recognized in the literature (cf. the survey by Sassenou and Mairesse, 1991). In columns (4) through (6) we repeat these regressions for a gross output specification of output. The (gross) output elasticities are similar to the estimates based on value added, but somewhat lower as expected.

The next two columns, (7) and (8) show similar results for a more general specification of the technology than the log-linear specification used in columns (1)-(6). Here we regress a productivity index on the stock of knowledge capital. This index of total factor productivity

[5]See Griliches (1979, 1995) and Hall and Mairesse (1995).

[6]See Hall and Mairesse (1995) for an extensive analysis of the sensitivity of the parameter estimates to changes in assumptions about this growth rate, the depreciation rate and other specification issues.

will be defined in section 4.1.2 below (cf. equation (17)). Again we find a significant relationship between R&D and productivity in the cross section, but R&D capital is insignificant when firm effects are included.

Finally in column (9) we regress productivity growth on R&D intensity. In this model the coefficient on R&D intensity can be interpreted as the private rate of return to R&D, see Griliches (1979). We find essentially a zero rate of return. The implied rates of return for the estimates in columns (1)-(8) are presented in table 3. We will comment on these rates of return in section 4.5 below.

To summarize, our analysis based on the standard framework shows results similar to what comparable studies have found for other countries. R&D is positively correlated with productivity levels, while the longitudinal correlation between R&D and productivity growth is much weaker, in some cases even statistically insignificant. The basic message is that R&D firms are ahead and tend to stay ahead in terms of both R&D and productivity. The dynamic, econometric model we present in the next section fits very well with such a pattern.

4 R&D, productivity and performance: the not-so-fixed effect model

4.1 R&D, productivity and dynamic performance

This section will present a modification of the standard econometric model used to estimate the relationship between R&D and productivity. The modification involves the R&D accumulation process discussed in section 2 as a replacement for the R&D stocks derived by perpetual inventory model. Our framework is attractive as the estimating equation is simple to implement, and the parameters have a structural interpretation. The presentation bellow follows Klette (1996) closely. Our framework is made up of three components: (i) a model of production; (ii) a simple specification of product demand; and (iii) the specification of knowledge accumulation, already discussed in section 2.

4.1.1 Production, R&D capital and *process* innovations

The first component of the modified framework is a model of short-run producer behavior, a specification that is based on the assumption of short-run, profit-maximizing behavior, allowing for scale economies and imperfect competition in the output market. In this section, we will use the term firm without making any distinction between plants and the line of business within a firm. The distinction between the plant and the line of business (within the firm) will be introduced when we present the estimating equation in section 4.1.4.

Consider a firm that produces an output (Q_t) by means of the three inputs, labor, materials and capital, according to the production function $A_t F(X_t)$, where X_t is a vector representing the three inputs $(X_t^l,\ l = L, M, C)$. Let a hat above a variable denote logarithmic deviations from a reference input-output vector, (Q_{0t}, X_{0t}); i.e. $\hat{q}_t = \ln(Q_t/Q_{0t})$. We will refer to this reference point as the *reference firm.* We have dropped the index referring to the firm (the subscript "i"). It can be shown that the following relationship holds under quite general conditions[7]:

$$\hat{q}_t = \sum_{l=L,M,C} \alpha_t^l \hat{x}_t^l + \widehat{a}_t \tag{10}$$

where $\alpha_t^l \equiv [\partial \ln(F_t)/\partial \ln(X_t^l) + \partial \ln(F_{0t})/\partial \ln(X_{0t}^l)]/2$. $\widehat{a}_t$ is the (logarithmic) productivity difference between the firm we consider and the reference firm.

With profit maximization, the output elasticity for a fully adjustable factor of production is equal to the markup (on marginal costs) times the factor's cost share, assuming price taking firms in the *factor* markets (see Klette, 1994a, for details). It follows that

$$\alpha_t^l = \mu(\theta_t^l + \theta_{0t}^l)/2 \equiv \mu\, \bar{\theta}_t^l, \tag{11}$$

where θ_t^l is the cost for factor l as a share of revenue, for the firm we consider; θ_{0t}^l is the corresponding share for the reference firm. μ is the markup, i.e. the ratio of price and marginal costs. It is not reasonable to assume capital to be fully adjusted in every period, so we should treat capital differently from the fully adjustable factors. If ϵ is the elasticity of scale, we have that the output elasticity of capital (α_t^C) can be expressed: $\alpha_t^C = \epsilon - \sum_{l \neq C} \alpha_t^l = \epsilon - \sum_{l \neq C} \mu \bar{\theta}_t^l$, where the last equality follows from (11). Inserting this expression and (11) into equation (10):

$$\hat{q}_t = \mu \sum_{l=L,M} \bar{\theta}_t^l (\hat{x}_t^l - \hat{x}_t^C) + \epsilon \hat{x}_t^C + \widehat{a}_t \tag{12}$$

We will decompose the productivity term $(\widehat{a}_t)$ into two parts: One term reflects productivity differences due to differences in knowledge capital $(\alpha^K \hat{k}_t)$, whereas the second term $(\hat{u}_t)$ captures the remaining differences in productivity:

$$\hat{q}_t = \mu \sum_{l=M,L} \bar{\theta}_t^l (\hat{x}_t^l - \hat{x}_t^C) \ + \ \epsilon \hat{x}_t^C + \alpha^K \hat{k}_t + \hat{u}_t. \tag{13}$$

α^K is the output elasticity of knowledge capital. This parameter reflects the opportunities for *process innovation.*

[7]See Klette (1994a).

4.1.2 Demand, R&D capital and *product* innovations

As usual with firm level data, we do not have information about real output, only nominal sales[8]. We will now show how to reformulate equation (13) in terms of nominal sales instead of real output. Let us start with a demand function with price, knowledge capital and other demand shifters as its arguments. A firm's knowledge capital is assumed to affect demand through differences in product quality. Consider a (first order) log-linear expansion of the demand function around the reference firm:

$$\hat{q}_t = \eta\hat{p}_t + \xi\hat{k}_t + \hat{d}_t, \tag{14}$$

where $\hat{p}_t$ and $\hat{k}_t$ are the firm's price and knowledge capital relative to the reference firm. η is the price elasticity of demand, while ξ is the elasticity of demand with respect to a change in the firm's relative "product quality". The parameter ξ also captures the relationship between knowledge and product quality. $\hat{d}_t$ is a demand shifter. From the relationship $S_t = P_tQ_t$, it follows that $\hat{s}_t = \hat{p}_t+\hat{q}_t$. Using this relationship, we can eliminate the unobservable $\hat{p}_t$ in equation (14):

$$\hat{q}_t = \frac{1}{\eta+1}\hat{d}_t + \frac{\eta}{\eta+1}\hat{s}_t + \frac{\xi}{\eta+1}\hat{k}_t. \tag{15}$$

Optimal price setting implies a markup: $\mu = \eta/(1+\eta)$. Using this expression and combining (13) and (15) to eliminate the unobservable $\hat{q}_t$, we have that

$$\hat{s}_t = \sum_{l=M,L} \theta_t^l(\hat{x}_t^l - \hat{x}_t^C) + \frac{\epsilon}{\mu}\hat{x}_t^C + \gamma\hat{k}_t - \frac{1}{\eta}\,\hat{d}_t + \frac{1}{\mu}\hat{u}_t, \tag{16}$$

where $\gamma = \alpha^K/\mu - \xi/\eta$ (notice that η, the price elasticity, is negative by definition). The two terms that make up the γ-parameter capture the effect of both process and product innovations.

Define the performance index:

$$\hat{a}_t \equiv \hat{s}_t - \sum_{l=M,L} \theta_t^l(\hat{x}_t^l - \hat{x}_t^C) - \hat{x}_t^C. \tag{17}$$

This performance index is essentially a Tornquist index for the Solow residual, except that sales ($\hat{s}_t$) has replaced real output ($\hat{q}_t$) in the Solow residual; see Klette (1996) for a discussion. The performance index will capture scale economies, market power and demand differences, in addition to productivity differences. This is clear if we rewrite equation (16) in terms of the performance index (17):

[8] Deflated sales will not alter the argument as long as the deflation is based on industry wide deflators. See Klette and Griliches (1996) for a discussion in a slightly different context.

$$\hat{a}_t = \left(\frac{\epsilon}{\mu} - 1\right)\hat{x}_t^C + \gamma\hat{k}_t - \frac{\hat{d}_t}{\eta} + \frac{\hat{u}_t}{\mu}. \tag{18}$$

4.1.3 R&D investment and the production of knowledge capital

Knowledge accumulation is assumed to take place according to (2). Since the log-linear relationship is assumed to hold for all firms we have that:

$$\hat{k}_{t+1} = (\rho - \nu)\hat{k}_t + \nu\hat{r}_t + \hat{v}_t, \tag{19}$$

where $\hat{v}_t$ captures stochastic elements in the innovation process. As above, a hat above a variable represents logarithmic deviations from the reference firm. Hence, the specification suggests that a firm's knowledge capital stock next year, measured *relative to the reference firm*, depends on its *relative* capital stock from the past, as well as the firm's *relative* R&D effort.

Note that though the accumulation equation for R&D capital collapses for zero R&D investment, our empirical analysis includes firms which do not report any R&D. We circumvent this problem by including a dummy variable for these firms. The interpretation is that these firms also accumulate knowledge, but not by means reported as formal R&D[9].

The term $(\rho - \nu)$ reflects the depreciation rate for the private (i.e. the appropriable) part of a firm's knowledge capital. Below, we will refer to $1 - (\rho - \nu)$ as the depreciation rate. $(\rho - \nu)$ determines *cet.par.* the speed of decay of a firm's knowledge advantage (or disadvantage)[10]. The $(\rho - \nu)$ parameter also captures scale economies in R&D. The ν-parameter alone reflects the innovative opportunities of R&D effort. Hence, the two parameters ρ and ν reflect three different aspects of the process for generating R&D capital; scale economies in R&D, depreciation, and the potency of R&D in generating new knowledge. This suggests that a more general specification of the production function for R&D capital might be desirable. We must leave this as a topic for future research.

Pakes and Ericson (1989), among others, have argued that firm specific stochastic elements in knowledge accumulation (in a broad sense) represent an important aspect of firm dynamics. The possibility of incorporating stochastic shocks in the knowledge accumulation process (cf. the last term in eq. 19), in a clean and consistent way, is a benefit of the alternative framework here as compared to the standard ("perpetual inventory") framework.

It might be undesirable to impose the assumption that there is a one-year lag between R&D and new profit making knowledge, as in (19). It is not difficult to generalize the specification

[9]An alternative way to handle firms that do not carry out R&D is to consider a knowledge accumulation process such as $K_{t+1} = K_t^{(\rho-\nu)}(R_t + \theta)^\nu$. This extension creates a non-linear estimation problem that we have not addressed in this paper.

[10]See Pakes and Schankerman (1984) for a discussion of knowledge depreciation. More precisely, $(\rho - \nu)$ is the speed of decay for the *logarithm* of the knowledge capital stock

in (4) (and (19)) with a more flexible lag-structure, i.e. $K_{it+1} = K_{it}^{(\rho-\nu_1)} R_{it}^{\nu_1} R_{it-1}^{\nu_2} R_{it-2}^{\nu_3} \cdots$ We will present some estimates with this more general specification below. However, as others have experienced before us, empirically it turns out to be hard to determine the appropriate lag structure, since R&D investments tend to be highly autocorrelated, as we showed in section 2.

4.1.4 The estimating equation: A not-so-fixed effect model

We can eliminate the unobservable knowledge capital stocks in equation (18) by using equation (19):

$$\hat{a}_{it} = (\rho - \nu)\hat{a}_{it-1} + \gamma\nu\hat{r}_{It-1} + \lambda_1\hat{i}_{it-1} + \lambda_2\hat{x}_{it-1}^{C} + \hat{e}_{it}. \tag{20}$$

The two first terms on the right hand side capture the essence of our model, while the two last terms are included to control for market power and scale economies[11]. Equation (20) is our estimating equation. We have in this equation introduced a notation that distinguishes between plants and the line-of-business (within a firm) to which the plant belongs. The subscript i refers to a plant, while the upper case subscript I refers to the line-of-business (within the firm) to which the plant belongs. If a firm operates several plants within a line-of-business, we assume that they all have access to the same knowledge capital stock; see Klette (1996) for a discussion[12].

The difference equation (20) corresponds to a dynamic process where there are persistent differences in performance between plants, but not quite as persistent as in the fixed-effect case. The equation portrays a process where there is a tendency for differences in productivity to disappear with time, if there are no differences in R&D effort. Externalities, i.e. diffusion of knowledge is the cause for this tendency to converge, in our interpretation. Hence, the property that an above average firm tend to decline to average performance reflect only a relative decline rather than an absolute decline - in other words, the average level of performance is persistently improving. We should emphasize that this tendency to convergence only holds when there are no differences in R&D effort. We argued, however, in section 2 that there is a feedback mechanism built into this model that will give incentives to preserve (cross sectional) differences in R&D effort over time. This suggest that the model can rationalize persistent differences in performance between firms. A complete dynamic analysis of the model presented here requires an analysis of the two coupled difference equations (9) and (20), a task beyond the scope of this paper.

[11] The two last terms have been manipulated to reduce the multicolinearity problem between the variables representing the capital stock in two subsequent years. This is done through the approximation $x_{it}^C = \ln X_{it}^C = \ln(X_{it-1}^C + I_{it-1}) \simeq \ln X_{it-1}^C + (I_{it-1}/X_{it-1}^C)$, where we have introduced the variable $i_{it-1} = I_{it-1}/X_{it-1}^C$. The parameters should then be interpreted as follows: $\lambda_1 = (\epsilon/\mu - 1)$ and $\lambda_2 = [1 - (\rho - \nu)](\epsilon/\mu - 1)$.

[12] See also Adams and Jaffe (1996). Notice that Adams and Jaffe (1996) do not have access to R&D broken down at the line-of-business level as we do.

We notice that equation (20) is similar to equations widely studied and estimated within the standard framework. As noticed in Klette (1996), equation (20) picks up two correlation patterns which are not new or surprising; i.e. that productivity growth is positively related to lagged R&D, and negatively related to initial productivity. The contribution of the present framework is to show how these two patterns can been related within a fully specified *structural* model.

4.2 Econometric issues

4.2.1 Data and variable construction

Our data sources were briefly presented in section 2.2; more details are available in appendix A. In the empirical analysis below where we present estimates based on equation (20), with the plant as the unit of observation. One major reason why we have chosen the plant rather than the line-of-business within each firm, is that there is a significant amount of corporate restructuring going on among R&D intensive firms[13]. This makes it hard to keep track of the firms over time, while the problem is less severe for the plants which keep their identification number irrespective of the changes in ownership and the corporate structure.

4.2.2 Instrumental variables, fixed effects and GMM

Equation (20) can not be estimated directly by OLS since the equation contains a lagged dependent variable and the error term is autoregressive[14], as (at least) a first-order moving average process the MA(1) form, by construction. The estimation is instead carried out by instrumental variables, or more precisely by GMM.

The model is estimated in levels. As instruments for the lagged endogenous variable we use lagged values of output and employment in levels or differences. The preferred specification is based on an instrument set in differences since specification tests, which we will present below, indicates that fixed effects are present. (Hence, the preferred specification of our not-so-fixed effect model also incorporates fixed effects.) See Blundell and Bond (1995) for an analysis of the advantage of estimation with instruments in differences when fixed effects are present in dynamic panel data models. No instrument is used for the R&D variable, as it is assumed to be determined before the knowledge shock (and the performance shock) is revealed. We will

[13]Griliches and Mairesse (1984) discussed this problem with firm level data, and argued that the problem might significantly affect the estimated rate of return to R&D capital. One tends to loose many of the most successful R&D performers when constructing R&D capital stocks from past R&D expenditures, as many of the most successful R&D performers tend to restructure more often than other firms. A major benefit of the not-so-fixed effect model presented in this paper is that it only requires short panels of R&D investment. This is a useful property when we want to trace the performance of restructuring firms. Klette (1996) exploits and discusses this aspect of the not-so-fixed effect model.

[14]See Griliches (1961).

present both formal overidentification tests and estimates based on alternative instrument sets below.

As the estimating equation is written in (20), there are some cross-coefficient restrictions that appear to provide a means for specification testing, and more efficient estimation of the parameters. However, one should notice that if the ratio between the scale elasticity and the markup (cf. ϵ/μ) changes between periods, this cross-coefficient restriction disappears.

4.3 The potency of R&D and persistent performance differences

4.3.1 Estimates from first differences

The first results from our estimation of equation (20) can be found in table 4[15]. For completeness, column (1) shows OLS results which for reasons explained above are biased. The instrument sets based on variables in levels, used in columns (2)-(4), are rejected in favor of instruments in differences used in columns (5)-(7). The results in columns (5),(6) and (7) are quite similar and imply a depreciation rate of 15-18 percent, and a statistically highly significant, positive effect of R&D on next periods productivity .

In table 5 we try to explore the timing pattern of R&D by including several lags of R&D. From columns (5)-(7) it is clear that the lag structure is difficult to identify. It is not surprising that we encounter this well known problem given the persistence in R&D intensities found in section 2.2.

4.3.2 Estimates from longer differences: Reducing problems with lag specification

To reduce the problems with the lag specification, we have estimated the model for three year productivity differences. We recognize that even though the timing issue favor longer differences, problems with sample selection pulls in the opposite direction. The survival rate is lower for the no-R&D plants as we have documented in appendix B; going to longer differences will consequently select a less representative group of no-R&D plants compared to the group of R&D plants.

The results based on the model for three year productivity differences can be found in table 6. The OLS results can again be rejected. There are large differences in the parameter estimate for the lagged dependent variable, when we compare the estimates based on instruments in levels (cf. col. 2 and 3) with the estimates based on instrument in growth rates (cf. col. 4 and 5). As the differences in these parameter estimates are large relative to their standard errors, it is clear that a formal Hausman test will reject the models based on instruments in levels. Our preferred

[15]The estimates have been obtained by means of the GAUSS-program DPD, developed by Manuell Arellano and Steve Bond; see Arellano and Bond (1988).

[15]The No-R&D dummy is positive indicating that plants with high R&D drive this result.

specification is thus column (4) which implies an annual depreciation rate similar to what we found using one year differences, 18 percent[16], and a highly significant, positive effect of R&D on productivity.

4.4 Parameter stability over time and across industries

4.4.1 Differences over time

It has been argued that the innovative opportunities and the potency of R&D has been declining over the last 10 to 20 years; see Griliches (1994) for a survey of this discussion based on evidence for the US. In Norway, it is well known that a number of the large firms in the R&D intensive electronics industry in Norway faced severe problems at the end of the 1980s, after some successful years in the early 1980s. Klette and Førre (1995) found that R&D intensive firms eliminated more jobs than other firms in the late 1980s, while the opposite was true in the first half of the 1980s. It is therefore interesting to know whether the potency of R&D investments has changed over the period we consider. The results in table 7 suggests, that if anything, R&D became more potent from 1987 onwards. The negative relationship between R&D and performance in terms of job creation documented in Klette and Førre, does not carry over when we consider performance in terms of productivity. Indeed, some of the improvements in performance and productivity for R&D firms might reflect labor saving.

4.4.2 Differences across industries

We have examined differences in the effect of R&D across industries. Tables 8 and 9 present our results from estimating the model industry by industry. Table 8 is based on instruments in levels, while table 9 is based on instruments in difference form. The estimated R&D coefficients are quite similar in the sets of estimates, while the estimated coefficients on the lagged dependent variable tend to be lower when we apply instruments based on differences. For most industries, a formal Hausman test based on this coefficient will tend to reject the specification in table 8.

The R&D coefficients presented in table 9 show that R&D investment is most important for performance in "Industrial chemicals and Pharmaceuticals" (ISIC 351-2) and "Plastic and petroleum products" (ISIC 354-6), while somewhat lower in the other industries. There are also significant differences in the depreciation rate of knowledge capital; cf. the coefficient on the lagged dependent variable. We find the lowest depreciation rate in "Machinery" (ISIC 382) and the highest depreciation rate in "Plastic and petroleum products" (ISIC 354-6).

[16] I.e., $0.18 = 1 - (.558)^{1/3} = 1 - .82$.

4.5 Rates of return to R&D investments

In this section, we will illustrate how equation (9) and the estimated coefficients can be used to estimate the rate of return to R&D investments. Rearranging terms in (9), we find that

$$\beta = \frac{w_{t-1}R_{t-1}}{\nu\gamma S_t + (\rho - \nu)w_t R_t}$$

or since $\beta = 1/(1+r)$:

$$r = \frac{\nu\gamma S_t + (\rho - \nu)w_t R_t}{w_{t-1}R_{t-1}} - 1 \tag{21}$$

Using the parameter estimates presented above and the summary statistics in table 10, we can calculate the right hand side of this expression and thereby estimate the rates of return to R&D investments. The discount factor β in equation (9) reflects the required rate of return to R&D investments, and corresponds therefore to an *ex-ante* rate of return. However, the variables dated t in equations (9) and (21) refer to the expected values at time $t-1$ (or more generally, at the time when the R&D investment decision for period $t-1$ is made). Since we use realized rather than expected values in our estimates of the rate of return, it is more correct to consider this rate of return as an *ex-post* rate.

As we noticed in figure 1, the distribution of R&D intensities across plants is highly skewed. We therefore calculate rates of return for mean and median values of the R&D intensities as presented in the summary statistics in table 10. The resulting rates of return are given in table 11.

In the first column we use the estimate of the structural parameters in table 4, column (6). For a plant with the mean R&D intensity and mean R&D growth our results imply a rate of return of 9 percent. For median values of R&D intensity and R&D growth the return is also 9 percent.

In the next column we use the estimate of the structural parameters in table 6, column (4). For a plant with the mean R&D intensity and mean R&D growth our results imply an annual rate of return of 11 percent. For median values of R&D intensity and R&D growth the return is 6 percent. We also give results for each industry using the structural parameters from table 9.

Considering the estimated private rates of return in table 11, they are quite low compared to estimates based on the standard model; see Griliches (1994,1995). The rates of return in table 11 are much closer to normal rates of return e.g. on physical investment[17] than the estimates that Griliches refers to. Taking the estimates in table 11 at face value, they e.g. suggest significantly smaller imperfection in the capital market than previous estimates.

[17]The rate of return on physical capital investment has been estimated to around 7 percent for the Norwegian economy.

In table 3, we have presented estimates for the rate of return to R&D investments based on the standard model. We can use these estimates to make a more clear cut comparison of the rate of return derived from the standard framework to the estimates based on our alternative specification. The results in columns 4-6 in table 3 are *a priori* most comparable to those we have presented in table 11[18]. We must recognize that the rates of return in table 3 are *gross* rates and should be adjusted for depreciation to be comparable to the results in table 11. Considering the rates of return for the mean output-R&D capital ratio in columns 4 and 5 in table 3, the estimates are much higher than the estimates in table 11. This is true even if we subtract a 15 percent depreciation rate from the estimates in table 3 (i.e. the depreciation rate used to construct the R&D capital stocks). It is, however, evident that the rates of return to R&D investment presented in table 3 are not very robust and that allowing for fixed effects in the estimation (as in columns 3, 6, 7 and 8) has a very dramatic effect on the rates of return. This is to a large extent also true for the estimates in table 11 based on our alternative specification. The lack of robust estimates of rates of return to R&D has been observed in a number of similar studies; see the survey by Mairesse and Sassenou (1991).

A striking pattern in table 11 is the large differences in the rates of return between industries. Since these are *ex-post* rates of return, this variation might reflect a substantial amount of randomness in the innovation process, that we also emphasized above. Similarly, the mean rate of return to R&D investment is much lower than the estimates for the median line of business. This suggests a distribution of rates of return skewed to the right. That is to say, a low fraction of firms experience rates of return to R&D that are sufficiently high to pull the average rate of return substantially above the median. This result is related to Schankerman and Pakes (1986) who also found that the value of innovations, measured by the value of patents, is highly skewed with a few very profitable innovations and a large fraction that are close to worthless. Clearly, the variations in our estimated rates of return to R&D investment could also reflect a problem with our framework.

Before we pull the interpretation of our estimates too far we should point out a caveat that our model shares with the standard framework. It is clear from equation (21) that a firm with sufficiently low R&D investment (cf. the denominator) relative to its sales, will have a high rate of return to its R&D (even if its planned R&D investment in the next period is zero). A similar problem is present in the standard model where the rate of return to R&D capital is estimated as proportional to the ratio of sales to R&D capital; a firm with little R&D capital, i.e. little past R&D investment will therefore have a high rate of return and vice versa. We find this implication of the model puzzling and we believe that it reveals a problem with the

[18]Since both are based on gross output rather than value added.

log-linear specification where the marginal product of knowledge capital is proportional to the average product of knowledge capital. This question deserves further analysis before too much is made out of estimated rates of return to R&D investment, whether the estimates are based on our empirical framework or the standard framework.

5 Conclusions

The point of departure for our analysis are some well known observations on the empirical patterns of R&D investment and productivity: First, there are substantial cross sectional differences in R&D activity within narrow industries, and these cross sectional differences tend to be quite persistent over time. Second, there are quite strong cross sectional correlations between R&D and productivity, while the longitudinal correlations are much weaker. We have argued that the first observation questions the validity of the standard framework for R&D productivity studies that treat the accumulation of knowledge capital as identical to the accumulation of physical capital (based on the perpetual inventory model). We also argued that the empirical pattern of R&D investment can be better accommodated by a simple, alternative accumulation process for R&D capital that allows for a positive complementarity between already acquired knowledge and current R&D in the generation of new knowledge[19].

The second step in our analysis shows how this alternative specification of knowledge accumulation leads to a simple, structural and dynamic econometric model, where next year's performance (roughly speaking, productivity) depends on current performance and current R&D activity. We have estimated this model on a new data set, where plant level production data have been linked with R&D data broken down by product line within each firm. Our empirical framework merges the cross sectional and the longitudinal patterns identified in the second observation mentioned above, and permits a structural interpretation of the estimated coefficients. We find that the appropriable part of R&D capital depreciates quite rapidly, with an estimated annual depreciation rate around 18 percent on average. We should point out that this high rate of depreciation of the appropriable part of R&D capital suggests significant spillover effects according to our model. Our estimates also show that R&D investment has a significant effect on firm (or plant) performance, but the estimated private rates of return to R&D investment is substantially lower than the rates of return found in many of the studies surveyed by Griliches (1995). However, we point out a puzzle or problem with our estimates of the rate of return to R&D investment that we have not managed to resolve. That is, the rate of return to R&D

[19]We have shown that intertemporal complementarity in R&D can rationalize the observed persistency in R&D. However, persistency in R&D does not necessarily imply persistency in innovations. Indeed, Geroski, Van Reenen and Walters (1996) have shown, on the basis of innovation data for UK, that there is little persistence in *large* innovations. There might be a high degree of persistence in smaller innovations, while the persistence in major breakthroughs and innovations is low.

investment is estimated to be very high for firms that invest very little in R&D relative to their sales. This implication of the model is due to the assumption of diminishing returns to knowledge capital for all values of this capital, an assumption or property that our alternative specification shares with the standard framework.

References

Adams, J. and A. Jaffe (1996): Bounding the Effects of R&D: An Investigation Using Matched Establishment-Firm Data, *RAND Journal of Economics,* 27.

Arellano, M. and S. Bond (1988): Dynamic Panel Data Estimation Using DPD - A Guide for Users, Institute for Fiscal Studies, Working Paper 88/15, London.

Bailey, M., C. Hulten and D. Campbell (1992): "Productivity Dynamics in Manufacturing Plants" *Brookings Paper on Economic Activity, Microeconomics.* 187-268.

Blundell, R. and S.Bond (1995): Initial Conditions and Moment Restrictions in Dynamic Panel Data Models. Working Paper no. 95/17., Institute of Fiscal Studies.

Bound, J., C. Cummins and Z. Griliches (1984): Who does R&D and Who Patents? In Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: Chicago University Press.

Cohen, W.M. and S. Klepper (1992): The Anatomy of Industry R&D Intensity Distributions. *American Economic Review*, 82, 773-99.

Geroski, P., J. Van Reenen and C. F.Walters (1996): How Persistently do Firms Innovate? CEPR Discussion Paper no. 1433.

Griliches, Z. (1961): A Note on Serial Correlation Bias in Estimates of Distributed Lags. *Econometrica*, 29, 65-73.

———— (1979): Issues in Assessing the Contribution of Research and Development to Productivity Growth. *Bell Journal of Economics*, 10, 92-116.

———— (1988): Productivity Puzzles and R&D: Another Nonexplanation. *Journal of Economic Perspectives*, 2, 9-21.

———— (1994): Productivity, R&D, and the Data Constraint. *American Economic Review*, 84, 1-23.

———— (1995): R&D and Productivity: Econometric Results and Measurement Issues. In P. Stoneman (ed.): *Handbook of the Economics of Innovation and Technical Change.* Oxford: Blackwell.

———— and J. Mairesse (1984): Productivity and R&D at the Firm Level. In Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago: Chicago University Press.

Hall, B.H. and F. Hayashi (1989): Research and Development as an Investment. NBER Working paper no. 2973.

Hall, B.H. and J. Mairesse (1995): Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms. *Journal of Econometrics*, 65, 263-94.

Jones, R. (1995): Models of R&D and Endogenous Growth. *Journal of Political Economy*, 103.

Klette, T.J. (1994a): Simultaneous Estimation of Price-Cost Margins and Scale Economies from a Panel of Microdata. Discussion Papers no. 127, Statistics Norway.

———— (1994b): R&D, Spillovers and Performance among Heterogeneous Firms. An Empirical Study Using Microdata. Discussion Papers no. 133, Statistics Norway.

———— (1996): R&D, Scope Economies and Plant Performance. *RAND Journal of Economics,* 27, 502-522.

———— and S.E. Førre (1995): Innovation and Job Creation in a Small Open Economy: Evidence from Norwegian Manufacturing Plants 1982-92. Discussion Papers 159, Statistics Norway.

———— and Z. Griliches (1996): The Inconsistency of Common Scale Estimators when Output Prices are Unobserved and Endogenous, *Journal of Applied Econometrics,* 11, 343-361.

Mairesse, J. and M. Sassenou (1991): R&D and Productivity: A Survey of Econometric Studies at the Firm Level. *STI Review no. 8*, Paris: OECD.

Milgrom, P. Y. Qian and J. Roberts (1991): Complementarities, Momentum, and the Evolution of Modern Manufacturing. *American Economic Review, Papers and Proceddings,* 81.

Nelson, R.R. (1988): Modelling the Connections in the Cross Section between Technical Progress and R&D Intensity. *RAND Journal of Economics*, 19, 478-85.

Pakes, A. and N. Ericson (1989): Empirical Implications of Alternative Models of Firm Dynamics. NBER Working paper no. 2893.

Pakes, A. and M. Schankerman (1984): An Exploration into the Determinants of Research Intensity. In Z. Griliches (ed.): *R&D, Patents and Productivity*, Chicago University Press (Chicago).

Penrose, E.T. (1959): *The Theory of the Growth of the Firm.* Basil Blackwell (Oxford).

Romer, P.M. (1990): Endogenous Technological Change. *Journal of Political Economy*, 98, 71-102

Schankerman, M. and A. Pakes (1986): Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period. *Economic Journal*, 96, 1052-76.

Shen, T.Y. (1970): Economies of Scale, Penrose Effect, Growth of Plants and their Size Distribution. *Journal of Political Economy*, 78, 702-16.

Stokey, N.L. and R.E. Lucas with E. Prescott (1989): *Recursive Methods in Economic Dynamics.* Harvard University Press (Cambridge, U.S.)

Uzawa, H. (1969): Time Preference and the Penrose Effect in a Two-Class Model of Economic Growth. *Journal of Political Economy*, 77, 628-52

Appendix A: Data

Data sources

Our empirical analysis uses merged data from the Manufacturing Statistics and R&D surveys. The Manufacturing Statistics of Statistics Norway is an annual census of all plants in the Norwegian manufacturing industry. See Halvorsen et al. (1991) for documentation. From this source we use information on outputs and other inputs than R&D. The unit of observation in the analysis is the plant, so to each plant we merge the R&D expenditures at the line of business level within each firm.

Information about R&D expenses at the line of business level of each firm is obtained from R&D surveys for the years 1982, -83, -84, -85, -87, -89 and -91. This survey was carried out by the Norwegian Research Council for Science and Technology (NTNF) until 1989 and by Statistics Norway in 1991. See Skorge et al. (1996) for definitions and industry level figures.

Sample construction

Our analysis covers the period 1980-92 and the following industries: "Chemicals" (ISIC 35)[20], "Basic metals" (ISIC 37) and "Metal products" (ISIC 38). These industries account for almost all R&D in Norwegian manufacturing[21].

Since the coverage of the R&D survey is quite low for firms with less than 20 employees, our analysis covers only plants which belong to firms with at least 20 employees in at least one year in the sample period. Note that the analysis also includes plants which report no R&D. Since we use lagged variables as instruments when estimating the model, we limit the analysis to plants where we have at least four consecutive years of observations.

Variable construction

Output is measured as the value of gross production corrected for taxes and subsidies. Inputs are labor (man hours), materials including energy, rentals and fire insurance value of capital. Constructing our performance index, all nominal variables are deflated using industry level deflators from Norwegian national accounts.

In addition to investments, each plant reports the fire insurance values and rental costs for machinery and buildings. We have constructed a simple filter to eliminate some of the noise that is known to exist in the fire insurance values. The capital values have been transformed to rental costs by a standard user cost formula, to account for the differences in depreciation between buildings and machinery and to make it possible to sum these costs together with the

[20] We have not included "Petroleum refining" (ISIC 353) in our analysis, as it is a sector with a very low R&D intensity (in Norway).

[21] In 1991, these industries accounted for 91 per cent of total R&D expenditures in manufacturing.

reported rental costs of capital. The final measure of capital for year t is the mean of capital values at the end of years $t-2$, $t-1$, and t

The R&D variable includes all intramural and extramural R&D expenditures. The R&D expenditures are deflated with a wage deflator. To avoid double counting of the R&D inputs, we have pulled out R&D labor from the man hours before constructing the performance measure. Finally for the three years without a R&D survey, we interpolate R&D expenses plant by plant.

Appendix B: A descriptive analysis of R&D and performance

Correlations between R&D and miscellaneous variables

Table 12 displays results from regressions of each of the main variables in this analysis on various sets of dummy variables. This allows us to test whether differences between R&D and no-R&D plants are statistically significant, and to control for industry and time differences. The entries in table 12 were calculated by performing variants of the following regressions:

$$\ln(\text{variable}) = \lambda + \beta_{\text{R\&D}} D_{\text{R\&D}} + \beta_{\text{High R\&D}} D_{\text{High R\&D}} ,$$

where 'variable' refers the variables labor productivity, capital intensity, TFP, production, hourly wages and investment per worker. The variable $D_{\text{R\&D}}$ is one if the the firm (more precisely, the line-of-business within the firm) carries out R&D investments and zero otherwise, while $D_{\text{High R\&D}}$ is one if the R&D investments are high [22], and zero otherwise. λ represents various time and industry dummies which are included in addition to the R&D dummies: For each variable we have carried out four regressions; including only year dummies, year times 3-digit ISIC industry dummies, year times 5-digit ISIC industry dummies, year times 5-digit ISIC industry and size dummies. The coefficient $\beta_{\text{R\&D}}$, then, represent the percentage by which the average R&D firm differs from the average firm without R&D activity within the same "cell", as defined by the dummies included in the regression. $(\beta_{\text{R\&D}} + \beta_{\text{High R\&D}})$ is the corresponding difference for the average firm with high R&D investments. The numbers in the parentheses in table 12 are the standard errors from these regressions.

The table shows that compared with no-R&D plants, R&D plants have significantly higher labor productivity, capital intensity, production , wages per man hour, and investment per worker. Total factor productivity is higher only for high R&D plants.

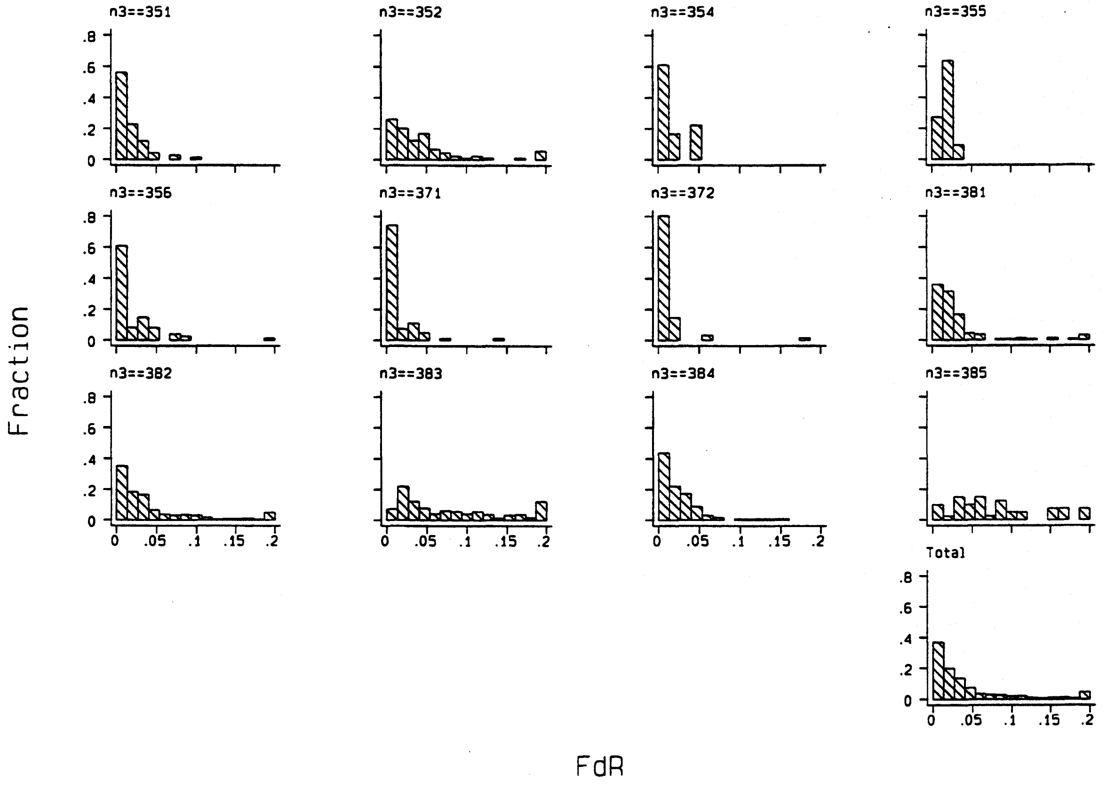
Exit patterns

Table 13 reveals a striking difference between R&D and no-R&D plants in their survival pattern: 62 percent of the R&D plants survive the whole 12-year period, while the corresponding number is 39 percent for the no-R&D plants. Table 14 shows results from a probit analysis of exit where we control for year, industry and size differences. The results in column (1) show that no-R&D plants have higher exit probabilities than R&D plants in the same industry. In column (3) we include employment, a measure of size, as an explanatory variable. This still leaves a clear difference in exit probabilities between R&D and no-R&D plants.

[22]High R&D is defined as an R&D intensity exceeding 1 percent.

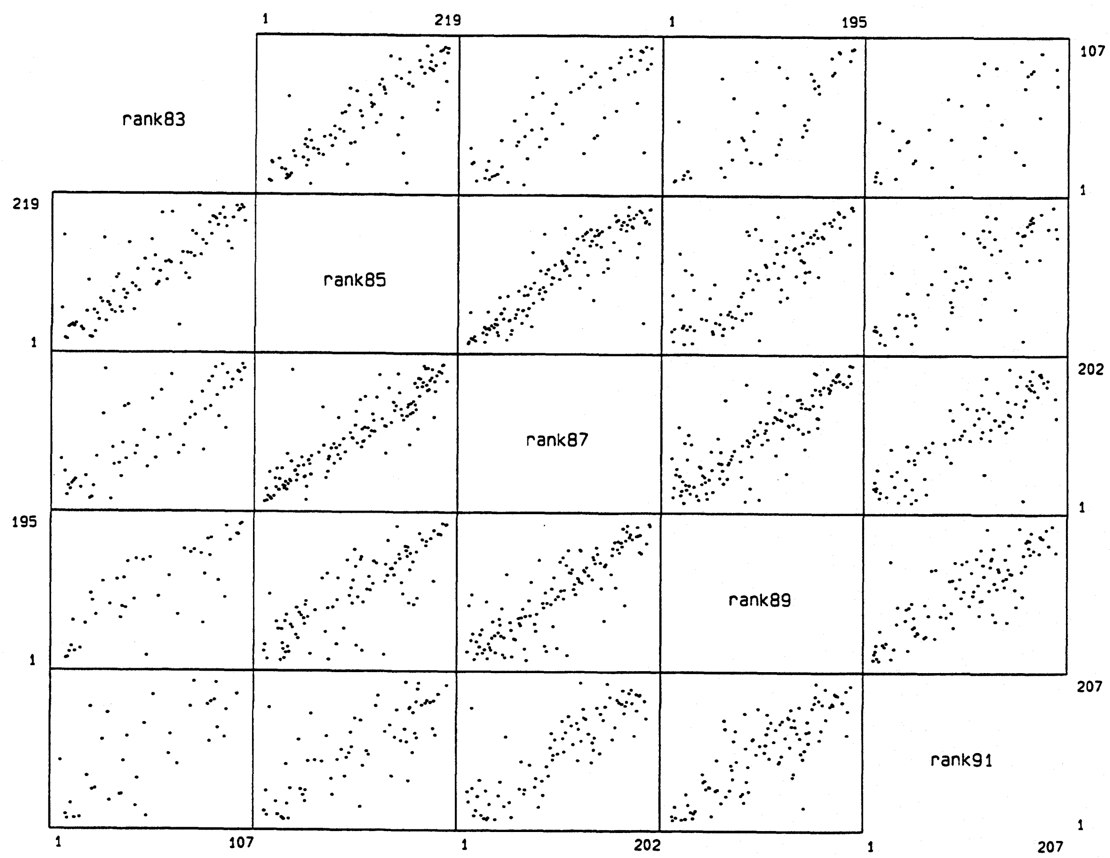
Figures

Figure 1: Distribution of R&D Intensities by Industry



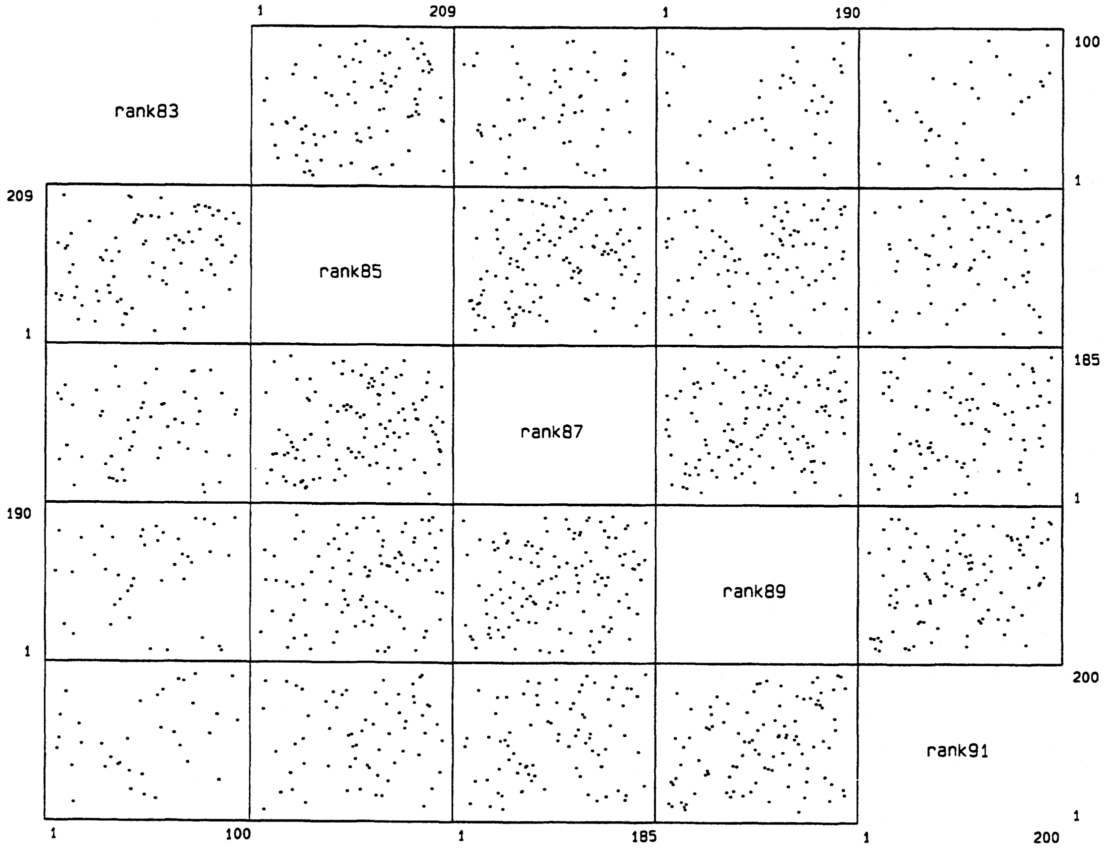
Notes: Observations at line of business level. Observations with no R&D not shown.

Figure 2: Ranks of R&D Intensities. Time t vs. t+2, t+4, t+6, t+8



Notes: Observations at line of business level. Observations with no R&D not shown.

Figure 3: Ranks of Investment Intensities. Time t vs. t+2, t+4, t+6, t+8



Notes: Observations at line of business level. Observations with no R&D not shown.

Tables

Table 1: Matrix of Transition Probabilities for Categories of R&D-Intensity

t	t+2 No R&D	1	2	3	4	Total
No R&D	2170	65	46	68	47	2396
	90.57	2.71	1.92	2.84	1.96	100.00
1	42	98	17	4	1	162
	25.93	60.49	10.49	2.47	0.62	100.00
2	38	24	42	16	3	123
	30.89	19.51	34.15	13.01	2.44	100.00
3	29	3	20	73	28	153
	18.95	1.96	13.07	47.71	18.30	100.00
4	21	1	4	26	91	143
	14.69	0.70	2.80	18.18	63.64	100.00
Total	2300	191	129	187	170	2977
	77.26	6.42	4.33	6.28	5.71	100.00

Table 2: Results for Log-linear Models with Standard R&D Capital Accumulation

	Dependent Variable								
	ln(Value added)			ln(Gross output)			$\hat{a}_t$		$\Delta\hat{a}_t$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ln(Materials)				.556	.528	.485			
				(.007)	(.007)	(.011)			
ln(Capital)	.201	.125	.127	.073	.040	.051			
	(.007)	(.009)	(.017)	(.005)	(.005)	(.006)			
ln(Labor)	.819	.903	.781	.349	.423	.397			
	(.008)	(.010)	(.023)	(.006)	(.008)	(.014)			
ln(R&D Capital)	.066	.053	.018	.036	.030	.004	.018	-.002	
	(.005)	(.005)	(.007)	(.002)	(.002)	(.003)	(.002)	(.002)	
R&D Intensity									.004
									(.020)
D(R&D Capital=0)	.422	.335	.105	.243	.198	.020	.115	-.005	
	(.039)	(.038)	(.054)	(.019)	(.019)	(.020)	(.015)	(.017)	
D(R&D Int.=0)									.000
									(.003)
Time dummies	No	Yes	Yes	No	Yes	Yes	No	No	No
Industry dummies	No	Yes	No	No	Yes	No	No	No	No
Fixed effect	No	No	Yes	No	No	Yes	No	Yes	No
Adjusted R^2	.90	.91	.94	.97	.98	.99	.02	.52	.00
Observations	11289	11289	11289	11343	11343	11343	11343	11343	9970

Notes: R&D Intensity is defined as R&D investment divided by the average of output in period t and $t+1$.

Table 3: Implied rates of return to R&D investments from models in table 2

	ln(Value added)			ln(Gross output)			$\hat{a}_t$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
For mean value of Output/R&D Capital	24%	22%	2%	51%	45%	6%	28%	-17%
For median value of Output/R&D Capital	6%	5%	1%	11%	10%	1%	6%	-4%

Table 4: One Year Differences, GMM-Results

Dependent variable: $\hat{a}_{t+1}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\hat{a}_t$	.6604	.8828	.9342	.9310	.8248	.8497	.8461
	(.0171)	(.0144)	(.0161)	(.0186)	(.0265)	(.0307)	(.0355)
$\hat{r}_t$	.0115	.0061	.0046	.0048	.0065	.0066	.0069
	(.0021)	(.0013)	(.0013)	(.0013)	(.0017)	(.0015)	(.0017)
$\hat{i}_t$	.0311	-.0043	-.0109	-.0093	-.0028	-.0075	-.0062
	(.0121)	(.0095)	(.0105)	(.0111)	(.0108)	(.0117)	(.0126)
$\hat{x}_t^C$	-.0025	-.0020	-.0015	-.0013	-.0022	-.0026	-.0028
	(.0018)	(.0009)	(.0009)	(.0010)	(.0012)	(.0012)	(.0012)
D($R_t = 0$)	.0641	.0358	.0264	.0281	.0364	.0361	.0381
	(.0144)	(.0090)	(.0087)	(.0089)	(.0111)	(.0109)	(.0113)
Obs	9991	9991	9991	9991	9991	9991	9991
Sargan/Hansen		p=.002	p=.016	p=.059	p=.000	p=.000	p=.000
IV	OLS	$n_{t-1,2,..}$	$n_{t-2,3,..}$	$n_{t-3,4,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-2,3,..}$	$\Delta n_{t-3,4,..}$
		$q_{t-1,2,..}$	$q_{t-2,3,..}$	$q_{t-3,4,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-2,3,..}$	$\Delta q_{t-3,4,..}$

Notes:Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 5: One Year Differences, GMM-Results, Extended R&D-lags

Dependent variable: $\hat{a}_{t+1}$

$\hat{a}_t$	.8310
	(.0267)
$\hat{r}_t$	.0023
	(.0039)
$\hat{r}_{t-1}$	.0026
	(.0059)
$\hat{r}_{t-2}$	-.0013
	(.0034)
$\hat{i}_t$	-.0088
	(.0123)
$\hat{x}_t^C$	.0023
	(.0012)
D($R_t = 0$)	.0101
	(.0239)
D($R_{t-1} = 0$)	.0140
	(.0366)
D($R_{t-2} = 0$)	-.0012
	(.0228)
Wald $\hat{r}_t = \hat{r}_{t-i} = 0$	p=.156
Obs	8552
Sargan/Hansen	p=.011
IV	$\Delta n_{t-1,2,..}$
	$\Delta q_{t-1,2,..}$

Notes: Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 6: Three Year Differences, GMM-Results

Dependent variable: $\hat{a}_{t+3}$

	(1)	(2)	(3)	(4)	(5)
$\hat{a}_t$	.4476	.7176	.7989	.5576	.6206
	(.0222)	(.0301)	(.0408)	(.0571)	(.0698)
$\ln(\sum R_t)$	.0160	.0102	.0086	.0136	.0127
	(.0031)	(.0025)	(.0025)	(.0027)	(.0027)
$\sum \hat{i}_t$	.0263	.0040	-.0044	.0112	.0070
	(.0108)	(.0099)	(.0110)	(.0111)	(.0124)
$\hat{x}_t^C$	-.0034	-.0030	-.0021	-.0046	-.0041
	(.0026)	(.0020)	(.0020)	(.0021)	(.0021)
$D(\sum R_t = 0)$	.1017	.0655	.0555	.0883	.0819
	(.0238)	(.0190)	(.0190)	(.0206)	(.0205)
Obs	7287	7287	7287	7287	7287
Sargan/Hansen		p=.018	p=.068	p=.001	p=.001
IV	OLS	$n_{t-1,2,..}$	$n_{t-2,3,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-2,3,..}$
		$q_{t-1,2,..}$	$q_{t-2,3,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-2,3,..}$

Notes: Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 7: Three Year Differences, GMM-Results, R&D effects by time period

Dependent variable: $\hat{a}_{t+3}$

$\hat{a}_t$	.5530
	(.0571)
$\ln(\sum R_t)D(81-86)$	.0132
	(.0026)
$\ln(\sum R_t)D(87-91)$	.0157
	(.0030)
$\sum \hat{i}_t$	.0117
	(.0111)
$\hat{x}_t^C$	-.0047
	(.0021)
$D(\sum R_t = 0)$	.0916
	(.0206)
Obs	7287
Sargan/Hansen	p=.002
IV	$\Delta n_{t-1,2,..}$
	$\Delta q_{t-1,2,..}$

Notes: Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 8: Three Year Differences, GMM-Results by Industry

Dependent variable: $\hat{a}_{t+3}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Industry	351-352	354-356	37	381	382	383	384-385
$\hat{a}_t$	.6391	.5726	.7396	.5000	.7958	.6532	.6981
	(.0149)	(.0355)	(.0208)	(.0493)	(.0392)	(.0271)	(.0374)
$\ln(\sum R_t)$	.0185	.0185	.0084	.0028	.0063	.0070	.0021
	(.0012)	(.0040)	(.0021)	(.0060)	(.0037)	(.0026)	(.0042)
$\sum \hat{i}_t$	.0833	-.0009	.0695	.0168	.0001	-.0052	.0423
	(.0104)	(.0055)	(.0104)	(.0106)	(.0132)	(.0106)	(.0175)
$\hat{x}_t^C$	-.0379	.0030	.0141	-.0122	.0040	-.0039	-.0025
	(.0021)	(.0028)	(.0022)	(.0037)	(.0029)	(.0035)	(.0033)
$D(\sum R_t = 0)$	.1275	.1355	.0480	.0282	.0374	.0182	.0109
	(.0123)	(.0307)	(.0159)	(.0462)	(.0303)	(.0215)	(.0312)
Obs	578	866	496	1451	1481	723	1488
Sargan/H.	p=.420	p=.390	p=.802	p=.253	p=.341	p=.296	p=.086
IV	$n_{t-1,2,..}$	$n_{t-1,2,..}$	$n_{t-1,2,..}$	$n_{t-1,2,..}$	$n_{t-1,2,..}$	$n_{t-1,2,..}$	$n_{t-1,2,..}$
	$q_{t-1,2,..}$	$q_{t-1,2,..}$	$q_{t-1,2,..}$	$q_{t-1,2,..}$	$q_{t-1,2,..}$	$q_{t-1,2,..}$	$q_{t-1,2,..}$

Notes: Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 9: Three Year Differences, GMM-Results by Industry

Dependent variable: $\hat{a}_{t+3}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Industry	351-352	354-356	37	381	382	383	384-385
$\hat{a}_t$	.4700	.2996	.8450	.4427	.7607	.7122	.4443
	(.0129)	(.0296)	(.0313)	(.0511)	(.0489)	(.0323)	(.0509)
$\ln(\sum R_t)$	.0178	.0148	.0075	.0062	.0067	.0039	.0080
	(.0013)	(.0034)	(.0021)	(.0061)	(.0046)	(.0025)	(.0046)
$\sum \hat{i}_t$	.1186	.0096	.0711	.0189	-.0045	.0070	.0521
	(.0107)	(.0073)	(.0056)	(.0106)	(.0143)	(.0112)	(.0196)
$\hat{x}_t^C$	-.0382	-.0047	.0138	-.0128	.0031	-.0008	-.0064
	(.0016)	(.0027)	(.0029)	(.0039)	(.0037)	(.0041)	(.0040)
$D(\sum R_t = 0)$	.1317	.0984	.0510	.0526	.0308	.0007	.0510
	(.0128)	(.0262)	(.0131)	(.0463)	(.0371)	(.0219)	(.0332)
Obs	578	866	496	1451	1481	723	1488
Sargan/H.	p=.224	p=.161	p=.720	p=.599	p=.510	p=.347	p=.896
IV	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$	$\Delta n_{t-1,2,..}$
	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$	$\Delta q_{t-1,2,..}$

Notes: Robust standard errors in parentheses. Time, industry, age, foreign ownership and plant type dummies not reported.

Table 10: Summary Statistics

VARIABLE	SAMPLE	OBS.	MEAN	MED.	S.DEV.
$\hat{a}_t$	All	11343	-0.050	-0.055	0.183
	R&D plants	4316	-0.026	-0.038	0.178
	No R&D plants	7027	-0.066	-0.066	0.185
i_t	All	11343	0.059	0.019	0.140
	R&D plants	4316	0.055	0.026	0.120
	No R&D plants	7027	0.061	0.014	0.150
$\hat{x}_t^C$	All	11326	9.557	9.502	1.793
	R&D plants	4316	10.586	10.530	1.706
	No R&D plants	7010	8.924	9.061	1.533
Employment	All	11343	108	48	189
	R&D plants	4316	185	93	269
	No R&D plants	7027	61	36	86
$\hat{r}_t$	R&D plants	4316	4.261	5.606	4.001
$w_t R_t / S_t$	R&D plants *	1609	0.126	0.038	0.982
$w_t R_t / w_{t-1} R_{t-1}$	R&D plants *	1187	1.248	1.094	1.310

Notes: * observations at line of business level.

Table 11: Rates of Return to R&D investments

	All Industries		Returns by Industry						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			351-352	354-356	37	381	382	383	384-385
Mean values	9%	11%	8%	4%	23%	0%	19%	15%	2%
Median values	9%	6%	7%	-3%	11%	-8%	7%	2%	-5%

Table 12: Can Differences Between R&D and No-R&D Firms be Explained by Industry and Size

	R&D	High R&D
log(Labor Productivity)		
(1)	0.2319 (0.0089)	0.0697 (0.0196)
(2)	0.1323 (0.0087)	0.1035 (0.0192)
(3)	0.0843 (0.0088)	0.0967 (0.0181)
(4)	0.0945 (0.0099)	0.0936 (0.0180)
Capital Intensity		
(1)	0.2367 (0.0145)	-0.2612 (0.0260)
(2)	0.1468 (0.0148)	-0.1006 (0.0253)
(3)	0.1419 (0.0146)	-0.0483 (0.0245)
(4)	0.1107 (0.0160)	-0.0476 (0.0244)
TFP		
(1)	-0.2491 (0.0087)	0.2371 (0.0165)
(2)	-0.0278 (0.0045)	0.0857 (0.0090)
(3)	-0.0382 (0.0044)	0.0733 (0.0087)
(4)	-0.0226 (0.0050)	0.0734 (0.0087)
log(Production)		
(1)	1.5617 (0.0239)	-0.2928 (0.0426)
(2)	1.3371 (0.0228)	-0.1472 (0.0440)
(3)	0.9425 (0.0204)	-0.0486 (0.0410)
(4)	0.1323 (0.0125)	0.0230 (0.0223)
log(Wages/Man Hour)		
(1)	0.0864 (0.0040)	0.0655 (0.0080)
(2)	0.0769 (0.0041)	0.0476 (0.0078)
(3)	0.0720 (0.0041)	0.0432 (0.0075)
(4)	0.0498 (0.0045)	0.0448 (0.0074)
Investment/Worker		
(1)	11.0879 (0.4996)	-1.1742 (0.9555)
(2)	7.6765 (0.4921)	1.1857 (0.9636)
(3)	5.8487 (0.5129)	1.2419 (0.9558)
(4)	4.3644 (0.5613)	1.3674 (0.9533)

Notes:
(1): Levels. Year dummies
(2): Levels. Year * industry(3-di) dummies
(3): Levels. Year * industry(5-di) dummies
(4): Levels. Year * industry(5-di) dummies and size dummies

Table 13: Observations per Plant

obs	R&D	No R&D	Total
4	148	660	808
	3.43	9.39	7.12
5	195	565	760
	4.52	8.04	6.70
6	162	558	720
	3.75	7.94	6.35
7	224	616	840
	5.19	8.77	7.41
8	128	664	792
	2.97	9.45	6.98
9	378	639	1017
	8.76	9.09	8.97
10	140	360	500
	3.24	5.12	4.41
11	253	253	506
	5.86	3.60	4.46
12	2688	2712	5400
	62.28	38.59	47.61
Total	4316	7027	11343
	100.00	100.00	100.00

Table 14: Probit Analysis of Exit

	(1)	(2)	(3)
$D(\bar{r}=0)$	.6675	.5691	.4099
	(.0427)	(.0550)	(.0572)
$\hat{r}_t$		-.0251	-.0135
		(.0094)	(.0098)
log(Employment$_t$)			-.2266
			(.0152)
Obs	15071	15071	15071
Pseudo R^2	.0863	.0871	.1130

Notes: Standard errors in parentheses. Dependent variable is 1 if plant exits in year $t+1$. Time dummies for each 3-digit industry included, but not reported.

Recent publications in the series Discussion Papers

42 R. Aaberge, Ø. Kravdal and T. Wennemo (1989): Unobserved Heterogeneity in Models of Marriage Dissolution.

43 K.A. Mork, H.T. Mysen and Ø. Olsen (1989): Business Cycles and Oil Price Fluctuations: Some evidence for six OECD countries.

44 B. Bye, T. Bye and L. Lorentsen (1989): SIMEN. Studies of Industry, Environment and Energy towards 2000.

45 O. Bjerkholt, E. Gjelsvik and Ø. Olsen (1989): Gas Trade and Demand in Northwest Europe: Regulation, Bargaining and Competition.

46 L.S. Stambøl and K.Ø. Sørensen (1989): Migration Analysis and Regional Population Projections.

47 V. Christiansen (1990): A Note on the Short Run Versus Long Run Welfare Gain from a Tax Reform.

48 S. Glomsrød, H. Vennemo and T. Johnsen (1990): Stabilization of Emissions of CO_2: A Computable General Equilibrium Assessment.

49 J. Aasness (1990): Properties of Demand Functions for Linear Consumption Aggregates.

50 J.G. de Leon (1990): Empirical EDA Models to Fit and Project Time Series of Age-Specific Mortality Rates.

51 J.G. de Leon (1990): Recent Developments in Parity Progression Intensities in Norway. An Analysis Based on Population Register Data

52 R. Aaberge and T. Wennemo (1990): Non-Stationary Inflow and Duration of Unemployment

53 R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Sweden

54 R. Aaberge, J.K. Dagsvik and S. Strøm (1990): Labor Supply, Income Distribution and Excess Burden of Personal Income Taxation in Norway

55 H. Vennemo (1990): Optimal Taxation in Applied General Equilibrium Models Adopting the Armington Assumption

56 N.M. Stølen (1990): Is there a NAIRU in Norway?

57 Å. Cappelen (1991): Macroeconomic Modelling: The Norwegian Experience

58 J.K. Dagsvik and R. Aaberge (1991): Household Production, Consumption and Time Allocation in Peru

59 R. Aaberge and J.K. Dagsvik (1991): Inequality in Distribution of Hours of Work and Consumption in Peru

60 T.J. Klette (1991): On the Importance of R&D and Ownership for Productivity Growth. Evidence from Norwegian Micro-Data 1976-85

61 K.H. Alfsen (1991): Use of Macroeconomic Models in Analysis of Environmental Problems in Norway and Consequences for Environmental Statistics

62 H. Vennemo (1991): An Applied General Equilibrium Assessment of the Marginal Cost of Public Funds in Norway

63 H. Vennemo (1991): The Marginal Cost of Public Funds: A Comment on the Literature

64 A. Brendemoen and H. Vennemo (1991): A climate convention and the Norwegian economy: A CGE assessment

65 K.A. Brekke (1991): Net National Product as a Welfare Indicator

66 E. Bowitz and E. Storm (1991): Will Restrictive Demand Policy Improve Public Sector Balance?

67 Å. Cappelen (1991): MODAG. A Medium Term Macroeconomic Model of the Norwegian Economy

68 B. Bye (1992): Modelling Consumers' Energy Demand

69 K.H. Alfsen, A. Brendemoen and S. Glomsrød (1992): Benefits of Climate Policies: Some Tentative Calculations

70 R. Aaberge, Xiaojie Chen, Jing Li and Xuezeng Li (1992): The Structure of Economic Inequality among Households Living in Urban Sichuan and Liaoning, 1990

71 K.H. Alfsen, K.A. Brekke, F. Brunvoll, H. Lurås, K. Nyborg and H.W. Sæbø (1992): Environmental Indicators

72 B. Bye and E. Holmøy (1992): Dynamic Equilibrium Adjustments to a Terms of Trade Disturbance

73 O. Aukrust (1992): The Scandinavian Contribution to National Accounting

74 J. Aasness, E. Eide and T. Skjerpen (1992): A Criminometric Study Using Panel Data and Latent Variables

75 R. Aaberge and Xuezeng Li (1992): The Trend in Income Inequality in Urban Sichuan and Liaoning, 1986-1990

76 J.K. Dagsvik and S. Strøm (1992): Labor Supply with Non-convex Budget Sets, Hours Restriction and Non-pecuniary Job-attributes

77 J.K. Dagsvik (1992): Intertemporal Discrete Choice, Random Tastes and Functional Form

78 H. Vennemo (1993): Tax Reforms when Utility is Composed of Additive Functions

79 J.K. Dagsvik (1993): Discrete and Continuous Choice, Max-stable Processes and Independence from Irrelevant Attributes

80 J.K. Dagsvik (1993): How Large is the Class of Generalized Extreme Value Random Utility Models?

81 H. Birkelund, E. Gjelsvik, M. Aaserud (1993): Carbon/energy Taxes and the Energy Market in Western Europe

82 E. Bowitz (1993): Unemployment and the Growth in the Number of Recipients of Disability Benefits in Norway

83 L. Andreassen (1993): Theoretical and Econometric Modeling of Disequilibrium

84 K.A. Brekke (1993): Do Cost-Benefit Analyses favour Environmentalists?

85 L. Andreassen (1993): Demographic Forecasting with a Dynamic Stochastic Microsimulation Model

86 G.B. Asheim and K.A. Brekke (1993): Sustainability when Resource Management has Stochastic Consequences

87 O. Bjerkholt and Yu Zhu (1993): Living Conditions of Urban Chinese Households around 1990

88 R. Aaberge (1993): Theoretical Foundations of Lorenz Curve Orderings

89 J. Aasness, E. Biørn and T. Skjerpen (1993): Engel Functions, Panel Data, and Latent Variables - with Detailed Results

90 I. Svendsen (1993): Testing the Rational Expectations Hypothesis Using Norwegian Microeconomic Data Testing the REH. Using Norwegian Microeconomic Data

91 E. Bowitz, A. Rødseth and E. Storm (1993): Fiscal Expansion, the Budget Deficit and the Economy: Norway 1988-91

92 R. Aaberge, U. Colombino and S. Strøm (1993): Labor Supply in Italy

93 T.J. Klette (1993): Is Price Equal to Marginal Costs? An Integrated Study of Price-Cost Margins and Scale Economies among Norwegian Manufacturing Establishments 1975-90

94 J.K. Dagsvik (1993): Choice Probabilities and Equilibrium Conditions in a Matching Market with Flexible Contracts

95 T. Kornstad (1993): Empirical Approaches for Analysing Consumption and Labour Supply in a Life Cycle Perspective

96 T. Kornstad (1993): An Empirical Life Cycle Model of Savings, Labour Supply and Consumption without Intertemporal Separability

97 S. Kverndokk (1993): Coalitions and Side Payments in International CO_2 Treaties

98 T. Eika (1993): Wage Equations in Macro Models. Phillips Curve versus Error Correction Model Determination of Wages in Large-Scale UK Macro Models

99 A. Brendemoen and H. Vennemo (1993): The Marginal Cost of Funds in the Presence of External Effects

100 K.-G. Lindquist (1993): Empirical Modelling of Norwegian Exports: A Disaggregated Approach

101 A.S. Jore, T. Skjerpen and A. Rygh Swensen (1993): Testing for Purchasing Power Parity and Interest Rate Parities on Norwegian Data

102 R. Nesbakken and S. Strøm (1993): The Choice of Space Heating System and Energy Consumption in Norwegian Households (Will be issued later)

103 A. Aaheim and K. Nyborg (1993): "Green National Product": Good Intentions, Poor Device?

104 K.H. Alfsen, H. Birkelund and M. Aaserud (1993): Secondary benefits of the EC Carbon/ Energy Tax

105 J. Aasness and B. Holtsmark (1993): Consumer Demand in a General Equilibrium Model for Environmental Analysis

106 K.-G. Lindquist (1993): The Existence of Factor Substitution in the Primary Aluminium Industry: A Multivariate Error Correction Approach on Norwegian Panel Data

107 S. Kverndokk (1994): Depletion of Fossil Fuels and the Impacts of Global Warming

108 K.A. Magnussen (1994): Precautionary Saving and Old-Age Pensions

109 F. Johansen (1994): Investment and Financial Constraints: An Empirical Analysis of Norwegian Firms

110 K.A. Brekke and P. Børing (1994): The Volatility of Oil Wealth under Uncertainty about Parameter Values

111 M.J. Simpson (1994): Foreign Control and Norwegian Manufacturing Performance

112 Y. Willassen and T.J. Klette (1994): Correlated Measurement Errors, Bound on Parameters, and a Model of Producer Behavior

113 D. Wetterwald (1994): Car ownership and private car use. A microeconometric analysis based on Norwegian data

114 K.E. Rosendahl (1994): Does Improved Environmental Policy Enhance Economic Growth? Endogenous Growth Theory Applied to Developing Countries

115 L. Andreassen, D. Fredriksen and O. Ljones (1994): The Future Burden of Public Pension Benefits. A Microsimulation Study

116 A. Brendemoen (1994): Car Ownership Decisions in Norwegian Households.

117 A. Langørgen (1994): A Macromodel of Local Government Spending Behaviour in Norway

118 K.A. Brekke (1994): Utilitarism, Equivalence Scales and Logarithmic Utility

119 K.A. Brekke, H. Lurås and K. Nyborg (1994): Sufficient Welfare Indicators: Allowing Disagreement in Evaluations of Social Welfare

120 T.J. Klette (1994): R&D, Scope Economies and Company Structure: A "Not-so-Fixed Effect" Model of Plant Performance

121 Y. Willassen (1994): A Generalization of Hall's Specification of the Consumption function

122 E. Holmøy, T. Hægeland and Ø. Olsen (1994): Effective Rates of Assistance for Norwegian Industries

123 K. Mohn (1994): On Equity and Public Pricing in Developing Countries

124 J. Aasness, E. Eide and T. Skjerpen (1994): Criminometrics, Latent Variables, Panel Data, and Different Types of Crime

125 E. Biørn and T.J. Klette (1994): Errors in Variables and Panel Data: The Labour Demand Response to Permanent Changes in Output

126 I. Svendsen (1994): Do Norwegian Firms Form Extrapolative Expectations?

127 T.J. Klette and Z. Griliches (1994): The Inconsistency of Common Scale Estimators when Output Prices are Unobserved and Endogenous

128 K.E. Rosendahl (1994): Carbon Taxes and the Petroleum Wealth

129 S. Johansen and A. Rygh Swensen (1994): Testing Rational Expectations in Vector Autoregressive Models

130 T.J. Klette (1994): Estimating Price-Cost Margins and Scale Economies from a Panel of Microdata

131 L. A. Grünfeld (1994): Monetary Aspects of Business Cycles in Norway: An Exploratory Study Based on Historical Data

132 K.-G. Lindquist (1994): Testing for Market Power in the Norwegian Primary Aluminium Industry

133 T. J. Klette (1994): R&D, Spillovers and Performance among Heterogenous Firms. An Empirical Study Using Microdata

134 K.A. Brekke and H.A. Gravningsmyhr (1994): Adjusting NNP for instrumental or defensive expenditures. An analytical approach

135 T.O. Thoresen (1995): Distributional and Behavioural Effects of Child Care Subsidies

136 T. J. Klette and A. Mathiassen (1995): Job Creation, Job Destruction and Plant Turnover in Norwegian Manufacturing

137 K. Nyborg (1995): Project Evaluations and Decision Processes

138 L. Andreassen (1995): A Framework for Estimating Disequilibrium Models with Many Markets

139 L. Andreassen (1995): Aggregation when Markets do not Clear

140 T. Skjerpen (1995): Is there a Business Cycle Component in Norwegian Macroeconomic Quarterly Time Series?

141 J.K. Dagsvik (1995): Probabilistic Choice Models for Uncertain Outcomes

142 M. Rønsen (1995): Maternal employment in Norway, A parity-specific analysis of the return to full-time and part-time work after birth

143 A. Bruvoll, S. Glomsrød and H. Vennemo (1995): The Environmental Drag on Long- term Economic Performance: Evidence from Norway

144 T. Bye and T. A. Johnsen (1995): Prospects for a Common, Deregulated Nordic Electricity Market

145 B. Bye (1995): A Dynamic Equilibrium Analysis of a Carbon Tax

146 T. O. Thoresen (1995): The Distributional Impact of the Norwegian Tax Reform Measured by Disproportionality

147 E. Holmøy and T. Hægeland (1995): Effective Rates of Assistance for Norwegian Industries

148 J. Aasness, T. Bye and H.T. Mysen (1995): Welfare Effects of Emission Taxes in Norway

149 J. Aasness, E. Biørn and Terje Skjerpen (1995): Distribution of Preferences and Measurement Errors in a Disaggregated Expenditure System

150 E. Bowitz, T. Fæhn, L. A. Grünfeld and K. Moum (1995): Transitory Adjustment Costs and Long Term Welfare Effects of an EU-membership – The Norwegian Case

151 I. Svendsen (1995): Dynamic Modelling of Domestic Prices with Time-varying Elasticities and Rational Expectations

152 I. Svendsen (1995): Forward- and Backward Looking Models for Norwegian Export Prices

153 A. Langørgen (1995): On the Simultaneous Determination of Current Expenditure, Real Capital, Fee Income, and Public Debt in Norwegian Local Government

154 A. Katz and T. Bye(1995): Returns to Publicly Owned Transport Infrastructure Investment. A Cost Function/ Cost Share Approach for Norway, 1971-1991

155 K. O. Aarbu (1995): Some Issues About the Norwegian Capital Income Imputation Model

156 P. Boug, K. A. Mork and T. Tjemsland (1995): Financial Deregulation and Consumer Behavior: the Norwegian Experience

157 B.E. Naug and R. Nymoen (1995): Import Price Formation and Pricing to Market: A Test on Norwegian Data

158 R. Aaberge (1995): Choosing Measures of Inequality for Empirical Applications.

159 T.J. Klette and S.E. Førre (1995): Innovation and Job Creation in a Small Open Economy: Evidence from Norwegian Manufacturing Plants 1982-92

160 S. Holden, D. Kolsrud and B. Vikøren (1995): Noisy Signals in Target Zone Regimes: Theory and Monte Carlo Experiments

161 T. Hægeland (1996): Monopolistic Competition, Resource Allocation and the Effects of Industrial Policy

162 S. Grepperud (1996): Poverty, Land Degradation and Climatic Uncertainty

163 S. Grepperud (1996): Soil Conservation as an Investment in Land

164 K.A. Brekke, V. Iversen and J. Aune (1996): Soil Wealth in Tanzania

165 J.K. Dagsvik, D.G. Wetterwald and R. Aaberge (1996): Potential Demand for Alternative Fuel Vehicles

166 J.K. Dagsvik (1996): Consumer Demand with Unobservable Product Attributes. Part I: Theory

167 J.K. Dagsvik (1996): Consumer Demand with Unobservable Product Attributes. Part II: Inference

168 R. Aaberge, A. Björklund, M. Jäntti, M. Palme, P. J. Pedersen, N. Smith and T. Wennemo (1996): Income Inequality and Income Mobility in the Scandinavian Countries Compared to the United States

169 K. Nyborg (1996): Some Norwegian Politicians' Use of Cost-Benefit Analysis

170 E. Berg, S. Kverndokk and K. E. Rosendahl (1996): Market Power, International CO_2 Taxation and Petroleum Wealth

171 R. Aaberge, U. Colombino and S. Strøm (1996): Welfare Effects of Proportional Taxation: Empirical Evidence from Italy, Norway and Sweden

172 J.K. Dagsvik (1996): Dynamic Choice, Multistate Duration Models and Stochastic Structure

173 J.K. Dagsvik (1996): Aggregation in Matching Markets

174 H.C. Bjørnland (1996): The Dynamic Effects of Aggregate Demand, Supply and Oil Price Shocks

175 A. Bruvoll and K. Ibenholt (1996): Future Waste Generation. Forecasts Based on a Macroeconomic Model

176 T. Fæhn and L. A. Grünfeld (1996) Recent Leaps Towards Free Trade. The Impact on Norwegian Industry and Trade Patterns

177 R. Barrell and K. A. Magnussen (1996): Counterfactual Analyses of Oil price Shocks using a World Model

178 E. Bowitz and S. I. Hove (1996): Business cycles and fiscal policy: Norway 1973-93

179 H.C. Bjørnland (1996): Sources of Business Cycles in Energy Producing Economies: The case of Norway and United Kingdom

180 K. Nyborg (1996): The Political Man and Contingent Valuation: Motives Do Count

181 E. Berg, S. Kverndokk and K.E. Rosendahl (1996): Gains from Cartelisation in the Oil Market

182 R. Aaberge and I. Aslaksen (1996): Decomposition of the Gini Coefficient by Income Components: Various Types of Applications and Interpretations

183 B. Bye (1996): Taxation, Unemployment and Growth: Dynamic Welfare Effects of "Green" Policies

184 T.J. Klette and F. Johansen (1996): Accumulation of R&D Capital and Dynamic Firm Performance: A Not-so-fixed Effect Model

Statistics Norway
Research Department
P.O.B. 8131 Dep.
N-0033 Oslo

Tel.: + 47 - 22 86 45 00
Fax: + 47 - 22 11 12 38

ISSN 0803-074X

Statistics Norway
Research Department