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On the Importance of R&D and Ownership for Productivity Growth.

Evidence from Norwegian Micro-Data 1976-85

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Abstract

The first part of this paper develops a semi-parametric growth accounting framework, which permits a simultaneous study of productivity changes, scale economies and market power, extending the approach developed by Hall (1988). The framework is consistent with the presence of quasi fixed-capital and requires only minimum restrictions on the technology. Applying this framework, the second part of the paper explores the impact of R&D investments and various ownership characteristics on changes in productivity at the establishment level, using a comprehensive set of Norwegian establishment data for the period 1976-85. On average I find no evidence for significant scale economies. There seems to be significant market power in only one out of five industries. R&D-investments are shown to have a positive impact on productivity, and yield a relatively high private rate of return. Corporate restructuring and public ownership do not seem to affect productivity.

1 Introduction

Growth in total factor productivity (TFP) is perhaps the single best measure of growth in (internal) efficiency in a production unit, whether it is a plant or a whole country. Solow (1957), Aukrust and Bjerke (1958) a.o. established that most of the long-run increases in economic welfare in industrialized countries have been due to growth in TFP. Jorgenson (1988) among others, has claimed that the decline in productivity growth from the mid 70s is among the most important puzzles for the economic profession.

This paper presents results from an analysis of the importance of R&D-investments, various kinds of ownership and changes in ownership, for productivity growth. In particular I examine differences in both productivity *levels* as well as productivity *growth rates* between publicly and privately owned firms. Similarly, the role of foreign ownership is explored. The importance of mergers and acquisitions is also investigated. To accomplish this task I have used a comprehensive, but largely unexplored data set covering Norwegian manufacturing establishments for the period 1976 to 85[1].

The significance of R&D for productivity growth at the firm and establishment level has been firmly documented by now[2]. The advantage of the study presented here compared to much of the related literature, is that I

[1] Griliches and Ringstad (1971) and Ringstad (1971,1974) used essentially the same data source, covering a different period. See Klette (1991) for a more comprehensive documentation of this data set.

[2] See Griliches (1988) for references to the literature. Lichtenberg and Siegel (1989) have provided a study from the U.S. with a similar level of disaggregation as the one presented here.

have access to disaggregated firm level data. This makes it possible to distinguish between a firm's production and R&D activities in different lines of business.

By now there is a large empirical and theoretical literature studying differences in internal efficiency between private and public firms[3]. No clear cut conclusion about the relative performance has emerged in the literature. The present study presents an econometric investigation of possible differences in productivity *levels* and/or *growth rates* between privately and publicly owned firms.

Another potentially important distinction in terms of ownership is between domestic and foreign ownership. Recent theory on multinational companies emphasizes these companies role for the diffusion of new technology between countries[4]. I have examined whether this is visible in terms of (significant) differences in either higher productivity levels or higher productivity growth rates in foreign owned firms.

The role of the market for corporate control and corporate restructuring as instruments to provide internal efficiency has been an important issue both among politicians and in the economic profession during the last decade[5]. During the last 10-15 years the numbers of corporate restructurings, in particular mergers and acquisitions, have grown rapidly in most Western

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[3]A survey of some relevant references are provided by Merchand et. al (1984). Vickers and Yarrow (1988) also survey some of the literature and discuss case by case the experiences obtained from the privatization program in the U.K. during the last decade.

[4]See e.g. Helpman (1984) and Grossman and Helpman (1989).

[5]There is by now a large literature on the significance of the market for corporate control for (internal) efficiency in firms. See e.g. Scherer (1988) for a survey of the literature.

countries. Figure 1 illustrates the boom in corporate restructuring in Norway from 1981 onwards. Whether this development reflects social or only private gains is far from a settled question. This paper examines the impact of corporate restructuring on productivity growth in the years after the restructuring has taken place.

2 The theoretical model

This section presents a semi-parametric framework for productivity measurement, drawing on and extending the approach developed by Hall (1988). While Hall focuses on the estimation of mark-ups in the absence of scale economies, this paper will be concerned with the joint estimation of mark-ups, scale economies and the contribution of various explanatory variables for productivity growth. This section shows how to perform this task and define and measure total factor productivity (TFP) when there are (i) several and non- separable outputs and inputs, (ii) non-neutral technological change, (iii) scale economies, (iv) a quasi-fixed factor and (v) imperfect competition[6].

The starting point of this analysis is a transformation function for a technology with several inputs and outputs. I assume that this transformation function has finite first derivatives (locally). As discussed by Panzar (1989), the production technology of a firm (or any other production unit) can be represented by such a transformation function under weak regularity condi-

[6] The present analysis focuses on the primal (technology) side of the problem. Recently, Morrison (1989) has shown how to correct the traditional TFP-measure for elements (iii)-(v), by investigating the dual (cost) side of the problem.

tions. The transformation function can be expressed as follows

$$\phi(z, y) = 0. \tag{1}$$

where z and y denote the vectors of inputs and outputs. If we differentiate equation (1), we obtain

$$\sum_{i \in N} \phi_i dz_i + \sum_{j \in M} \phi_j dy_j = 0. \tag{2}$$

N and M are the sets of inputs and outputs, while the subscripts on ϕ denote the partial derivatives. Equation (2) can be rewritten

$$\sum_{i \in N} \phi_i z_i \dot{z}_i + \sum_{j \in M} \phi_j y_j \dot{y}_j = 0. \tag{3}$$

where I have introduced the notation that a dot above a variable represents the corresponding logarithmic differentials, e.g:

$$\dot{z}_i \equiv \frac{dz_i}{z_i}. \tag{4}$$

Let us assume that the inputs can be decomposed into observed factor inputs (x) and (unobserved) factor productivity (a) as follows [7]

$$z_i = a_i x_i \quad i \in N. \tag{5}$$

x_i could for instance be man-hours, while a_i reflects effort, skills etc. Consequently

$$\dot{z}_i = \dot{a}_i + \dot{x}_i. \tag{6}$$

[7] i.e. I investigate the case of *factor augmenting technical change.*

Combining equations (3) and (6) and rearranging terms we obtain

$$\sum_{j\in M} v_j \dot{y}_j = \sum_{i\in N} s_i' \dot{a}_i + \sum_{i\in N} s_i' \dot{x}_i. \tag{7}$$

where

$$s_i' \equiv -\frac{\phi_i z_i}{\sum_{k\in M} \phi_k y_k} \tag{8}$$

$$v_j \equiv \frac{\phi_j y_j}{\sum_{k\in M} \phi_k y_k}. \tag{9}$$

As is well known, under profit maximization the marginal rates of transformations should be proportional to the marginal revenues for each of the outputs, and marginal costs for each of the inputs. Let us assume that the firm determines inputs, considering input prices to be fixed[8]. Let me for the moment neglect the issue of quasi-fixed factors, which will be discussed below. Then we have

$$v_j = \frac{(1-1/\epsilon_j)p_j y_j}{\sum_{k\in M}(1-1/\epsilon_k)p_k y_k}, \tag{10}$$

and

$$s_i' = \frac{w_i x_i}{\sum_{k\in M}(1-1/\epsilon_k)p_k y_k} \tag{11}$$

where 'ϵ_j' is the elasticity of demand for output j, w_i and p_j are the (shadow) prices of input i and output j.

Let μ define the average mark-up factor, i.e.

$$1/\mu = \sum_{k\in M}(1-1/\epsilon_k)\frac{p_k y_k}{\sum_{l\in M} p_l y_l} \tag{12}$$

[8]This is clearly the case with perfect competition. It is also true with a bargaining model where the unions and the firm negotiate about the wage rate, while the firm unilaterally determines the level of employment.

I will furthermore define the variable s_i such that

$$s_i \equiv \frac{s'_i}{\mu} = \frac{w_i x_i}{\sum_{k \in M} p_k y_k} \tag{13}$$

s'_i can also be expressed in an alternative way. Panzar (1989) has defined the degree of scale economies, η, in the multiple inputs, multiple outputs case in the following way

$$\eta \equiv -\frac{\sum_{i \in N} \phi_i z_i}{\sum_{j \in M} \phi_j y_j} \tag{14}$$

where a value of η larger, smaller or equal to unity corresponds to technologies exhibiting increasing, decreasing or constant returns to scale[9]. Combining equations (8) and (14),

$$s'_i = \eta \frac{w_i x_i}{\sum_{l \in N} w_l x_l} \tag{15}$$

Hence, we have that

$$\sum_{j \in M} v_j \dot{y}_j = \dot{A} + \mu \sum_{i \in N} s_i \dot{x}_i \tag{16}$$

where $\dot{A}$ is a generalized TFP-measure, obtained by weighing together the factor specific productivity growth rates:

$$\dot{A} = \sum_{i \in N} s'_i \dot{a}_i. \tag{17}$$

[9]Panzar defines the right hand side of equation (14) as the technological definition of returns to scale. He also shows that under fairly weak regularity conditions the technological definition will be equivalent to the definition of returns to scale from the cost side.

2.1 Unobserved factor prices, scale economies and imperfect competition

For some of the factors of production, e.g. capital, various kinds of rigidities makes it dubious to impute the marginal product from observed prices on new equipment, interest rates etc. The usual method to deal with this problem is to calculate the factor price/share of capital residually. This section examines how to do this correctly in the presence of non-constant returns and imperfect competition.

Let us focus on the case when there is only one fixed factor. In this case it is not too difficult to obtain the shadow price on the fixed factor and thereby correctly estimate the growth contribution from capital. Let factor x_k be predetermined at value K when the firm solves its short-run profit maximizing problem[10]. The Lagrangian associated with the (short run) profit maximizing problem will be

$$\mathcal{L} = \sum_{j \in M} p_j y_j - \sum_{i \in N} w_i x_i - \lambda \phi + \theta(K - x_k). \tag{18}$$

The instruments are $(y_1, \cdots, y_M, x_1, \cdots, x_N)$ while λ and θ are the Lagrange multipliers. By summing up the first order conditions arising from this maximization problem, it follows that

$$\begin{aligned} \sum_{i \neq k} w_i x_i + (w_k + \theta) x_k = & \quad -\lambda \cdot \textstyle\sum_{i \in N} \phi_i a_i x_i \\ = & \quad -\lambda \eta \textstyle\sum_{j \in M} \phi_j y_j \\ = & \quad \eta \textstyle\sum_{j \in M} (1 - \frac{1}{\epsilon_j}) p_j y_j. \end{aligned} \tag{19}$$

[10] K could follow from the firm solving a long-run profit maximizing problem. K will in general be a function of time, and referred to as quasi fixed.

The second equality follows from the definition of returns to scale (equation (14)). The third equality follows from the first order conditions. By rearranging terms in equation (19) one finds that the shadow price on the fixed factor can be expressed as follows:

$$w_k + \theta = \frac{1}{x_k}\left(\eta \sum_{j \in M} p_j y_j (1 - \frac{1}{\epsilon_j}) - \sum_{i \neq k} w_i x_i\right). \tag{20}$$

Using equation (12), it follows that

$$\frac{(w_k + \theta)x_k}{\sum_{j \in M} p_j y_j} = \eta/\mu - \sum_{l \neq k} s_l. \tag{21}$$

Inserting equation (21) into equation (16), we obtain

$$\sum_{j \in M} v_j(\dot{y}_j - \dot{x}_k) = \dot{A} + \mu \sum_{i \neq k} s_i(\dot{x}_i - \dot{x}_k) + (\eta - 1)\dot{x}_k \tag{22}$$

Below an empirical version of this model, which is estimated, will be presented. Let me first elaborate on the model a bit further by decomposing the generalized TFP-measure.

2.2 A decomposition of TFP-growth

Above I defined a (generalized) measure of TFP-growth. This measure was shown to capture increases in the flow of services per man-hour, unit of material inputs etc. An increased service flow from the different factors of production could be the result of technological advances, organizational innovations and improved management, increased effort etc. as discussed in the introduction. One of the important sources of technological progress is R&D-effort by the firms. I will follow the literature and approach the estimation of returns to R&D by means of the capital stock model of R&D (cf. Griliches, 1979). Let us assume that the productivity indices for the (ordinary) factors of production can be expressed as follows: $a_i = a_i(H, \psi), \ \ \forall i \in N$, where H is the firm's stock of technological know-how. ψ captures all other elements which affect the service flow per (measured) unit of input. Hence

$$da_i = \frac{\partial a_i}{\partial H} dH + \frac{\partial a_i}{\partial \psi} d\psi \tag{23}$$

In the appendix I have shown that

$$(\sum_{i \in N} \phi_i x_i \frac{\partial a_i}{\partial H} dH)/(\sum_{j \in M} \phi_k y_k) = -\rho\mu dH/(\sum_{j \in M} p_j y_j), \tag{24}$$

where ρ is the marginal revenue product of H. For the moment I will disregard changes in ψ. Applying the capital stock model of R&D, i.e. $dH = R - \delta H$ where R is R&D-expenditure, it follows that

$$\begin{aligned} \dot{A} \equiv & \ -\textstyle\sum_{j \in N}(\phi_j a_j x_j)\dot{a}_j/(\sum_{l \in M} \phi_l y_l) \\ = & \ \rho\mu dH/(\textstyle\sum_{j \in M} p_j y_j) \\ = & \ \rho\mu(R - \delta H)/(\textstyle\sum_{j \in M} p_j y_j) \\ \approx & \ \rho\mu R/(\textstyle\sum_{j \in M} p_j y_j). \end{aligned} \tag{25}$$

In the last approximation we assume that knowledge does not depreciate, i.e. $\delta \approx 0$[11].

When we allow for changes in ψ, we have that

$$\dot{A} = \rho\mu \frac{R}{\sum_{j \in M} p_j y_j} + \sum_{i \in N} s_i' \frac{\partial a_i}{\partial \psi} d\psi. \tag{26}$$

[11] Cf. Griliches (1979).

where the last term captures various other changes that affect productivity, such as capacity utilization and various ownership characteristics. In the next section I will present an empirical model where I have inserted equation (26) into (22).

3 The empirical model

Replacing $\dot{A}$ in equation (22), by using (26), is the next step to establish the empirical model. Motivated by the theoretical and empirical literature cited above, I will examine various variables with information about ownership charactersitics, to capture the unspecified last part of equation (26). This list of variables includes dummies for public versus private ownership, the occurrence of a recent corporate restructuring etc. To represent the last term on the right hand side of equation (26), the empirical model also includes a proxy for capacity utilization ($\Delta \log(h_t/n_t)$), time and industry dummies, and a random error term. The construction of these variables will be presented in more detail in the next section. As the discrete approximation to the growth rates in equation (22), I have used the log of the ratio between the observation for the variables in year t and t-1. The resulting model can be expressed as follows

$$\begin{aligned}\Delta \log(y_t/x_{kt}) = \quad & \mu \textstyle\sum_{i=L,M} s_{it}\Delta[\log(x_{it}/x_{kt})] + (\eta - 1)\Delta \log(x_{kt}) \\ & +(\rho\mu)(R_{t-\tau})/(\textstyle\sum_{j \in N} p_{j,t-\tau} y_{j,t-\tau}) + \gamma\Delta \log(h_t/n_t) \\ & + \text{ownership, time and industry dummies} + u_t \qquad (27)\end{aligned}$$

where u is an error term, assumed to be NIID across firms and over time. Δ represents $(1-$the lag-operator$)$.

The question of whether random productivity shocks would be correlated with right hand side variables is an old prominent question in the econometrics of producer behavior (see Mundlak and Hoch (1965) and Zellner et al. (1966)). That is, will (idiosyncratic) productivity shocks be correlated with growth rates in labor and material inputs, but not with capital inputs? Notice that productivity shocks transmitted equally to the growth rates of all the factors of production will not give any bias. That a positive productivity shock will be reflected in a higher growth in labor and material inputs seems not unlikely. To examine the possibility of an upward bias in my mark-up estimates, I will present estimates where I have treated the first variable on the right hand side of equation (27) as an endogenous variable. Growth in the number of employees per unit of capital has been used as the instrument. The (disputable) argument is that a positive productivity shock will be meet by an increase in manhours, while the number of employees is determined with the same sluggishness as capital inputs.

4 Data sources and construction of variables

The basic data source used in this analysis is the annual census carried out by The Division of Manufacturing Statistics in The Central Bureau of Statistics of Norway. Aggregate numbers and definitions for the census are reported in NOS (several years)[12]. Only establishments which belong to industry 38 ("Manufacture of metal products, machinery and equipment") are included in my study. I have used an unbalanced sample of annual observations for the period 1976-85 (inclusive). The sample includes only establishments with at least 5 employees. Plants with incomplete reports for the variables needed in the estimation have been eliminated. The main problem was lack of reports for the fire insurance values of the capital stock. This reduced the set of observations with about 50 percent. The theoretical model is derived under the assumption of small (annual) changes. Consequently, I decided to eliminate establishments reporting very large annual changes in production or inputs, reducing the sample by further 5 percents of the initial set of observations[13]. Table 1 reports some basic characteristics of the sample used in the estimation.

Price indices for gross production (seller prices) and materials (buyer prices) are taken from the Norwegian National Accounts. There are separate price indices for each of the production sectors in the National Accounts (approximately 100 manufacturing sectors).

The census data contain information about the establishments' company affiliation, as well as whether these companies are publicly owned. The data

[12]Klette (1991) reports various characteristics (mean, median, standard deviations etc.) of the distributions of output growth, growth in capital labor ratio , productivity growth etc. for individual industries.

[13]More precisely, plants reporting an annual growth rate for capital beyond 0.3 were eliminated. Observations where the difference in growth rates of outputs and inputs exceeded 0.3 were also eliminated. Experiments with different threshold values suggested that the results are not very sensitive to the chosen trimming procedure.

also include information about foreigners' share holding in the company to which the establishment belongs. Each establishment has been assigned an identification number containing a unique eight- digit code for its parent company. These identification codes are altered on the basis of information from the V.A.T.- register, the Employers' register (Arbeidsgiverregisteret) and supplementary information. Changes in the codes will reflect mergers and acquisitions, as well as some other changes in organizational status[14]. About 2.5 percent of the observations in the sample referred to plants going through a corporate restructuring[15]. There were 41 plants changing from foreign to domestic ownership, while 44 plants changed ownership the other way. 20 plants in the (trimmed) sample changed from private to public ownership, while 10 plants were privatized.

The census data were supplemented by observations on the companies' R&D-investment, broken down by line of business. These data have been collected by NTNF (The Royal Norwegian Council for Scientific and Industrial Research) on a census basis. I have matched observations on R&D from 1975 and 1979 with the production data. The matching was done at the company level. That is to say, I aggregated all R&D activities (in industry 38) and all production activities (in industry 38) before I estimated the R&D intensity[16].

[14]According to the written instruction on when to alter the company codes, the procedure is supposed to distinguish between mergers and acquisitions. In the first case both (all) the merging companies will get a new company code, while this is not the case in the case of an acquisition.

[15]Cf. fig. 1 for annual figures for the whole (untrimmed) sample.

[16]This procedure was chosen rather than constructing R&D intensities at a more disaggregated line of business level. In Klette (1989) I have discussed problems with the

The R&D intensity for a company was then attached to *all* establishments belonging to the same company.

The actual variables I have used are defined as follows:

(i) $\Delta \log(y_t)$. The growth rate in gross output was constructed as follows. The value of gross production at seller prices was obtained by deducting taxes and adding subsidies from gross production at market prices. When estimating the growth rates, gross output has been deflated by the price index from the National Accounts.

(ii) $\Delta \log(x_{kt})$. The growth rate of capital from year t to t-1 has been constructed by taking the investment in year t divided by the average of the reported fire insurance values (of machinery and buildings) in year t and t-1. From this growth rate I subtracted a depreciation rate derived from the National Accounts.

(iii) $\sum_{j=L,M} s_{jt} \Delta \log(x_j/x_{kt})$. L and M refers to labor and materials (including energy). The s_{jt}s were constructed as Tornquist indices, i.e. updating the share annually by taking the average share in year t and t-1. I used growth rate in manhours as the estimate for growth in labor inputs. The share of labor cost was corrected for R&D-personnel in order to avoid double counting [17]. This was done by multiplying the labor cost share with one minus the R&D-intensity, since the substantial share of R&D-expenditures tends to be labor costs.

classification and matching of R&D activities and production activities (in industry 38).

[17]Cf. Griliches (1979).

(iv) $R_{t-\tau}/(\sum_{i\in M} p_{i,t-\tau}y_{i,t-\tau})$, where $t-\tau$ refers to either 1975 or 1979. As described above, this R&D-intensity measure was constructed on a (2-digit) line of business basis. I have distinguished between privately financed and publicly financed R&D as reported by the firms. The R&D-intensity in 1975 was matched to observations on growth rates for the output etc. from 1977 to 1980 (inclusive), while the R&D-intensity in 1979 was matched to growth rates from 1981 onwards[18].

(v) $\Delta \log(h_t/n_t)$. Following Abott et al. (1988), I have experimented with the changes in the number of manhours per employee as a proxy for changes in capacity utilization.

(vi) Foreign ownership. This dummy variable was unity if foreigners owned at least 20 (or 50) percent of the plant's parent company.

(vii) Public ownership. This dummy variable was unity if central or local government owned at least 50 percent of the shares in the plant's parent company.

(viii) d(Foreign ownership). This dummy variable was unity if the firm had been reclassified from domestic to foreign ownership during the last three years.

[18] That is, I assume that there is at least a one year lag between R&D-expenditures and the first innovative results. This is partly justified by empirical studies (see Pakes and Shankerman (1984), and partly an econometric necessity in order to avoid simultaneity problems. Given the stability of R&D-investments over time, this is probably not an important issue.

(ix) d(Domestic ownership). This dummy variable was unity if the firm had been reclassified from foreign to domestic ownership during the last three years.

(x) d(Public ownership). This dummy variable was unity if the firm had been reclassified from private to public ownership during the last three years.

(xi) d(Private ownership). This dummy variable was unity if the firm had been reclassified from private to public ownership during the last three years.

(xii) Restructuring. This dummy variable was unity if the plant had changed the company code during the last three years.

5 Results

Table 2 reports estimation of various versions of the basic model. The row labeled 381 represents estimates of the average mark-up, μ, in the industry with ISIC-code 381 etc. (See table 1C for a description of the ISIC-codes). That is to say, in the estimation we allow for a separate mark-up in each 3-digit industry. The two first columns reports estimation of a model containing inputs (cf. variable (iii)) and time and industry dummies. The model presented in the next two columns allows for scale economies. The remaining columns include the intensity of (private) R&D and capacity utilization, d(H/N), as explanatory variables. Columns headed by the label OLS refer to OLS estimations, while IV refers to estimation by instrumental variables techniques (cf. discussion in section 3).

Table 3 presents estimates obtained from the estimation on various subsamples of the whole sample. The estimated model incorporates scale economies, R&D and the proxy for capacity utilization. The first 4 columns are obtained by estimation on the two periods 1977-80 and 1981-85. The last six columns refer to estimation on establishments of different sizes. The estimates in columns (5) and (6) are obtained from the sample of small establishments (at most 50 employees). The sample referred to in column (7) and (8) consists of establishments with between 50 and 200 employees, while the estimates in the last two columns are obtained from the large establishments (more than 200 employees).

The results presented in table 4 are obtained from the complete sample. The models estimated includes different ownership variables. The first two columns examine whether public or foreign owned establishments have different productivity *growth rates* from the remaining population of plants. The next two columns examine the same question in terms of productivity *levels.* This is done by considering the productivity performance of establishments which are transferred from private to public ownership and between foreign and domestic ownership, as well as the other ways around. The last two columns present results from an examination of the impact of corporate restructuring.

The mark-up

The estimates of the mark-ups are quite stable as we change the set of explanatory variables (cf. table 2), the sample of estimation (cf. table 3), and the method of estimation (columns labeled OLS vs. IV; instrumental variable methods). Let us focus on the main results in table 2, column (7) and (8). The conclusion which emerges from these estimations is that industry 383 ("Manufacture of electrical apparatus and supplies") has a mark-up significantly beyond unity. The estimate based on the whole sample is equal to 1.070 (s.e.= 0.012, see column (7)). The apparent significant mark-up in industry 384 in column (7) ("Manufacture of transport equipment") disappears when we take into consideration the possible simultaneity problem. For the remaining industries we are not able to reject the hypothesis of price taking behaviour[19].

The differences between the OLS and the IV-estimates are not significant for the mark-up estimates in industries 383, 384 and 385, indicating that the simultaneity issue discussed above is not an important problem for those industries. Alternatively, my instrument (growth in the number of employees per unit of capital) could be hampered with the same problem as the original variable (growth in the number of working hours and material inputs per unit of capital).

Compared to earlier works by Hall (1988), Domowitz et al. (1988) and to

[19]The IV estimate for the mark-up coefficent in industry 381 is significantly smaller than unity, which is hardly belivable. However, the differnce from unity is not large. I intend to investigate whether this result can be due to errors of measurement for the capital variable in future research.

some extent Abott et al. (1988), the mark-ups reported here are surprisingly small. Hall (1988), for instance, reports an average mark- up factor for U.S. manufacturing around 1.57 (std.dev.= 0.10). Abott et al. (1988) argue that Hall's model is misspecified due to the omission of an expalnatory variable; factor utilization. They present results from estimation of alternative specifications of the Hall model which support their view. However, Abott et al.'s estimates of the mark-up depend critically on their choice of model specification and the choice of instruments, and no clear cut conclusion about the size of the mark-up emerges from their results. It is interesting to notice that my mark-up estimates are not significantly affected by the introduction of the proxy for capacity utilization (cf. variable v), in contrast to the findings of Abbott et al.

Private returns to R&D

The estimated R&D-coefficient, ($\mu\rho$), is also remarkably stable as we alter both the estimation technique (OLS vs. IV), and model specification (cf. table 2). The coefficient suggests a private rate of return around 10-11 percent (after adjusting for the mark-up factor). This is quite high compared to estimated private rate of returns on physical capital in Norwegian manufacturing[20]. This high rate of return might be due to a higher risk-

[20]Bye and Frenger (1990) have recently estimated private (real) rates of return to physical capital around 7 percent for this sector ("Manufacturing of Metal Products, Machinery and Equipment").

premium on R&D investment[21].

There are some interesting changes in the R&D-coefficient as we consider different subsamples. First, the R&D-coefficient is not very precisely estimated in the period 1977-80, suggesting an uncertain relationship between differences in private R&D-expenditures (between firms) and differences in productivity in this period. The coefficient for the period 1981-85 is much more precisely estimated, and one is tempted to conclude that there was a closer relationship between R&D and productivity growth in this second period. The second interesting finding is that small firms (plants) have a much higher rate of return to their R&D-expenditures than larger firms (plants). One possible explanation for this result might be that small firms incorporate a higher risk premium on their R&D-expenditures than larger firms.

The average rate of return to R&D reported above is substantially smaller than those estimated from U.S. manufacturing panel data[22]. Most of those studies have found private rates of return to company funded R&D beyond 20 percent (often substantially so). It is interesting to note that the study by Lichtenberg and Siegel (1989), which is based on a sample with a level of disaggregation similar to the one used here, obtains estimates for the rate of return on R&D about as low my estimates. Lichtenberg and Siegel also

[21]One should keep in mind that a significant share of the R&D for the manufacturing sector in Norway is carried out in governmental labs. The R&D activity in these labs are heavily subsidized by public funds. So the rates of return reported here overestimate the returns to *total* R&D expenditures. However, the social benefits from R&D expenditures might exceed those captured here due to externalities etc.

[22]See Lichtenberg and Siegel (1989, table 7 and 8) for a survey.

find that R&D had a stronger impact on productivity growth in the early 80s compared to the (late) 70s. However, my finding that smaller firms earn a higher return on R&D is contrary to their conclusion.

I have also estimated the private rate of return to publicly financed R&D. It turned out not to be significantly different from zero. This finding is consistent with the results reported for U.S. manufacturing. In the U.S. the general result is that publicly financed R&D do not give rise to significant productivity growth for the firms carrying out the research [23]. Notice however, that publicly financed R&D in my sample amounts to a negligible share of the total R&D-investments reported.

Scale economies and capacity utilization

The estimations suggest that there on average are no significant scale economies *for the ordinary factors of production* in my sample. This claim seems to be true also when we consider the different plant sizes separately (cf. table 3, columns 5-10)[24]. Notice that the scale coefficent, η, refers to the ordinary factors of production (capital, labour and materials). With constant returns to scale to the ordinary factors of production, the (overall) technology will exhibit increasing returns when R&D is taken into account as another productive factor.

[23]See e.g. Lichtenberg and Siegel (1989).

[24]This result runs contrary to the findings of Griliches and Ringstad (1971, appendix A.12-A.15) who found significant elements of increasing returns in this industry. They considered observations from 1963. While I have incorporated the possibility of permanent productivity differences between firms, they did not.

The proxy for capacity utilization on the other hand turns out highly significant with an estimate of the coefficent about -0.11 (std.dev. = 0.008, cf. table 2, column 8). The sign of this coefficient is surprising compared to the general consensus and the work of other researchers. The results suggest that productivity increases as the working day is shortened.

Abbott et al. (1988) argue that changes in hours per man should be included to adjust for changes in the utilization of the capital stock. However, as have been argued by several researchers, the most consistent way to deal with this issue is to estimate a shadow price on capital[25]. I have shown above that the model estimated here is consistent with attaching the appropriate shadow price to capital. Consequently, further adjustments for the changes in utilization of capital should not be necessary[26]. However, due to labor hoarding one can argue that the marginal product of labor is smaller than the wage rate in slumps and vice versa. This is another part of the argument for procyclical productivity changes, which question the sign of my estimate. However, the issue of capacity utilization and productivity growth is not the central focus of the present study. Neither do the inclusion of changes in hour per man significantly affect the other estimated parameters in my model. I will not pursue the rationalization of my estimate any further at this stage.

[25]Cf. Berndt and Fuss (1986).

[26]One should notice that Abbott et al. (1988) estimate a model without using the observed shares for labor and materials (the s_{it}'s). Incorporating an additional proxy for the degree of capacity utilization of capital might be justified in their case, while it is not in my model.

The effects of foreign and public ownership

As is evident from the results reported in table 4, columns 1 and 2, neither foreign nor public ownership seem to have a significant effect on productivity *growth rates* [27]. I have experimented with two definitions of foreign ownership, one with a limit at 20 percent foreign ownership and another with a 50 percent limit. The results did not differ (the results reported here refers to a 20 percent limit).

The results reported in table 4, columns 3 and 4, indicate that firms changing from private to public ownership or vice versa do not experience any systematic changes in productivity growth in the following years. This result suggests that there is no significant difference in productivity *levels* between privately and publicly owned firms in my sample. On the other hand, changes between domestic and foreign ownership do seem to have a significant, negative effect on productivity growth. The estimates indicate that changes in both directions are negatively related to productivity growth in the following years. This finding is not consistent with the theory of multinational corporations as institutions for technological transfer. Neither does this finding fit easily with most other theories on the real effects of changes in ownership. A possible rationalization of this finding could be that our model distorts the true causality in the process. That is to say, possibly firms obtaining a below average productivity growth, are the ones

[27] This interpretation of the results should be treated with some caution. If for instance foreign owned firms carry out more R&D than domestically owned firms, there might still be an argument that productivity growth is higher in foreign owned firms. I intend to investigate such "second order" effects in future research.

that are the objects for ownership changes (between foreign and domestic owners). And if a recovery of the productivity performance is not evident during the following three years, a negative correlation between these changes in ownership and productivity growth after the change would be the result. A more careful investigation of this (causality) issue is left for future research.

The significance of corporate restructuring

Table 4, columns 5 and 6, show that corporate restructuring have a positive, but not statistically significant effect on productivity. Related studies from U.S. manufacturing have ended up with different conclusions. This finding is consitent with Scherer's view that on average takeovers (in U.S. manufacturing) do not seem to produce any long term improvement in profitability (Scherer, 1988). On the other hand, Lichtenberg and Siegel (1987) found a positive effect of corporate restructuring on productivity growth in a study very similar to the one presented here.

Productivity changes over time

Figure 2 presents the estimated time dummies (they all had std. deviations around 0.005) adjusted for the overall average value of all the time and industry dummies (which was almost identically equal to zero). The low productivity growth during the years 81-83 coincides with a slump in the Norwegian economy.

6 Conclusions

The theoretical part of this paper derives a semi-parametric framework for econometric investigations of productivity growth for firms with quasi-fixed capital, operating with non-constant returns to scale in an imperfectly competitive environment. This represents an extension of previous work on growth accounting, in particular the recent work by Hall (1988). This framework has been used to estimate mark-ups and scale economies, and examine different potential sources of productivity growth in Norwegian manufacturing. The following conclusions have emerged:

- There is no significant scale economies to the ordinary factors of production (capital, labour and materials) in any of the samples of plants examined in this study.
- Only in one of the five industries considered in this study do the estimates suggest that the firms have significant market power.
- R&D-investments have a significant, positive effect on productivity growth. Such investments seem to yield a private rate of return beyond the returns to investments in physical capital.
- Small firms appear to earn a higher rate of return on their R&D-investments.
- The impact of R&D on productivity growth was more pronounced in the early 80s as compared to the late 70s.

- The evidence presented in this study reveals a tendency for productivity to improve in plants which have been subjects to a corporate restructuring. However, the effect is not statistically significant.

- This study does not support claims about significant differences in productivity growth rates or productivity levels between privately and publicly owned firms in this industry.

- The study suggests that firms owned by foreign capital do not have a productivity growth performance which is significantly different from firms owned by domestic capital.

- The study indicates that changes between domestic and foreign ownership are negatively correlated to the productivity growth performance after the change in ownership.

Appendix: The Rate of Return to R&D-capital

Inserting the first order conditions for profit maximization into equation (2), and using equation (5), gives after some rearrangements of terms

$$\sum_{j\in M} p_j(1-1/\epsilon_j)dy_j - \sum_{i\in N} w_i dx_i \;\; = d\pi \;\; = -\lambda \sum_{i\in N} \phi_i x_i da_i, \tag{28}$$

where λ is the Lagrange multiplier associated with the profit maximization problem (cf. section 2.1). If we consider the changes in the a_is to be due to changes in the R&D-capital stock, H, then $da_i = \partial a_i/\partial H dH$. It follows that

$$\frac{d\pi}{dH} \equiv \rho = -\lambda \sum_{i\in N} \phi_i x_i \frac{\partial a_i}{\partial H} \tag{29}$$

where consequently ρ is the marginal revenue product of H. From the first order conditions for profit maximization and using the definition in (12), one can show that

$$\sum_{j\in M} \phi_j y_j = \frac{1}{\mu\lambda} \sum_{j\in M} p_j y_j. \tag{30}$$

Combining equations (29) and (30)

$$(\sum_{i\in N} \phi_i x_i \frac{\partial a_i}{\partial H} dH)/(\sum_{j\in M} \phi_k y_k) = -\mu\rho \frac{dH}{\sum_{j\in M} p_j y_j}. \tag{31}$$

Q.E.D.

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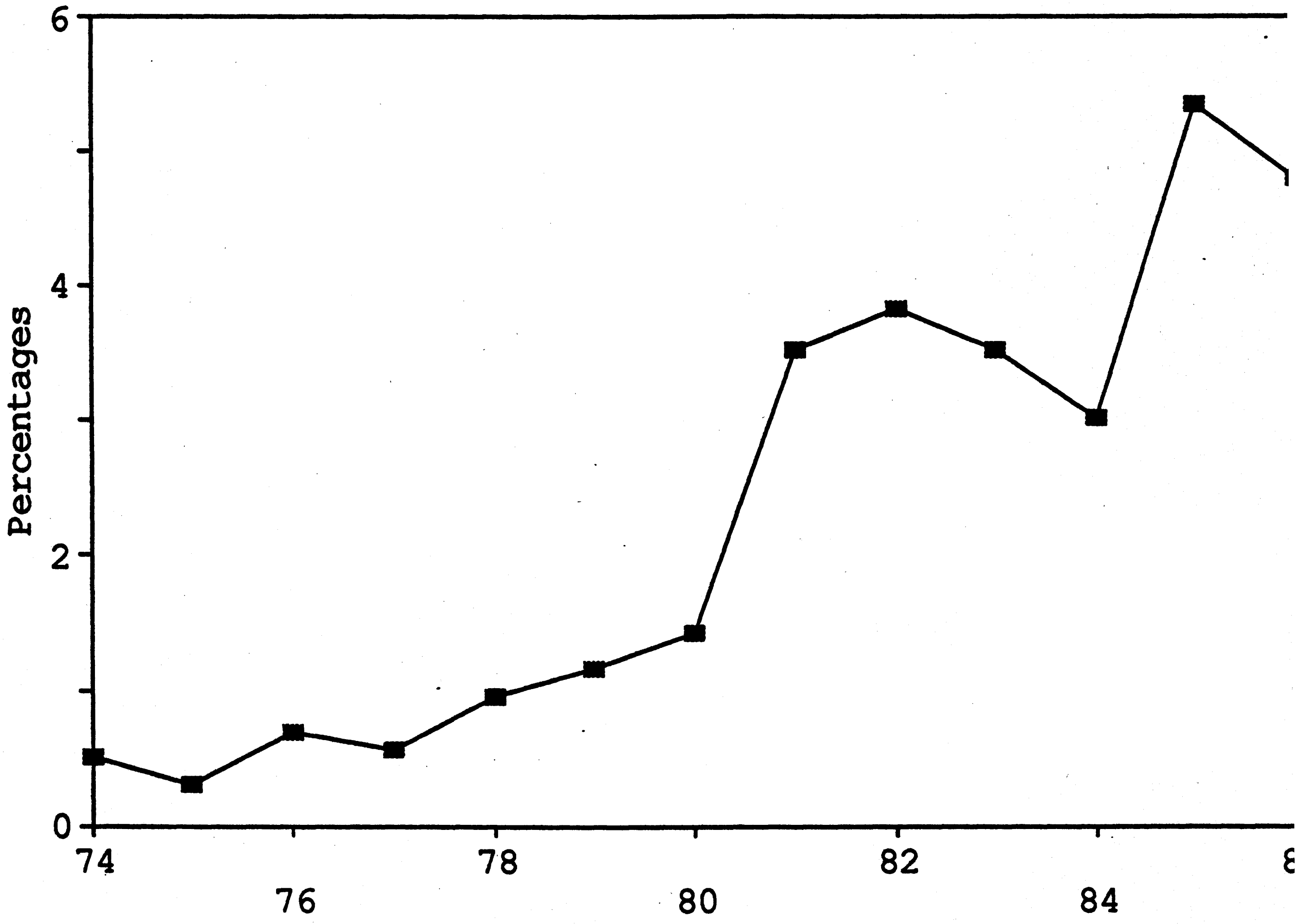

Figure 1: The share of plants beeing subject to corporate restructurings in industry 38.

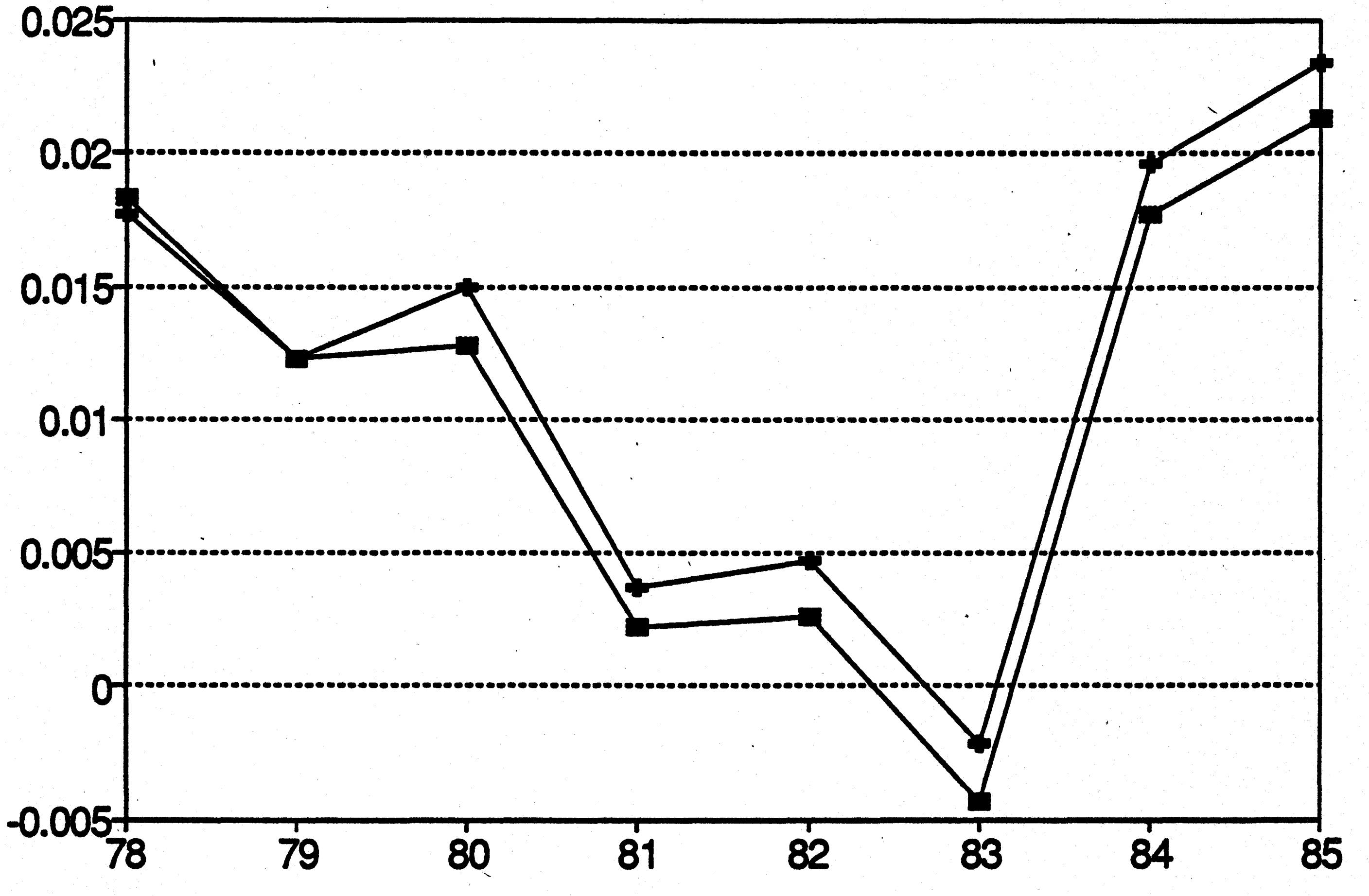

Figure 2: The estimated time dummies. The crosses refer to OLS estimation, while the other line refers to IV estimation of the basic model.

Table 1A: Characteristics of the sample distribution of variables used in the analysis.

Sample	Complete sample		1977-80		1981-85	
Variable	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
$\Delta\log(y_t/x_{kt})$	0,016	0,296	0,008	0,186	0,023	0,230
$\Delta\log(x_{kt})$	-0,005	0,067	-0,002	0,045	-0,008	0,049
$\Delta\log(x_t/x_{kt})$	0,010	0,273	-0,001	0,171	0,018	0,212
$\Delta\log(h_t/n_t)$	-0,003	0,127	-0,012	0,087	0,005	0,091
R&D-int.	0,005	0,038	0,003	0,011	0,007	0,036
Sample	Small plants		Medium plants		Large plant	
Variable	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
$\Delta\log(y_t/x_{kt})$	0,023	0,252	0,006	0,129	-0,023	0,086
$\Delta\log(x_{kt})$	-0,007	0,058	0,001	0,028	-0,001	0,017
$\Delta\log(x_t/x_{kt})$	0,015	0,231	-0,000	0,119	-0,025	0,082
$\Delta\log(h_t/n_t)$	-0,002	0,117	-0,004	0,043	-0,008	0,026
R&D-int.	0,002	0,017	0,013	0,030	0,021	0,014

Table 1B: Some further characteristics of the employed sample.

	Total sample #obs.	%	Small plants #obs.	%	Medium plants #obs.	%	Large plants #obs.	%
R&D-plants[1]	1268	10,1	218	2,4	602	24,8	448	51,3
Foreign owned (20%)[2]	594	4,7	207	2,2	263	10,9	124	14,2
Foreign owned (50%)[2]	457	3,6	181	2,0	201	8,3	75	8,6
Public owned	740	5,9	420	4,5	193	8,0	127	14,6

1) This refers to plants affiliated to companies reporting R&D-investments
2) 20 % and 50 % indicate the level of foreign capital required for a firm to be classified as foreign owned.

Table 1C: ISIC-codes

3-digit ISIC-code	Name	# obs.
381	Manufacture of metal products, except machinery and equipment	4552
382	Manufacture of machinery	3025
383	Manufacture of electrical apparatus and supplies	1265
384	Manufacture of transport equipment	3585
385	Manufacture of professional and scientific instruments, photographic and optical goods	131

Table 2: Estimation results from various versions of the basic model

	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV	(7) OLS	(8) IV
381	0.993	0.992	0.992	0.991	0.993	0.991	1.008	0.978
	(0.007)	(0.010)	(0.007)	(0.010)	(0.007)	(0.010)	(0.007)	(0.010)
382	0.986	1.009	0.986	1.009	0.986	1.008	1.000	1.000
	(0.007)	(0.012)	(0.007)	(0.012)	(0.007)	(0.012)	(0.007)	(0.012)
383	1.060	1.075	1.059	1.074	1.059	1.074	1.070	1.070
	(0.012)	(0.017)	(0.013)	(0.017)	(0.013)	(0.017)	(0.012)	(0.017)
384	1.019	1.008	1.019	1.007	1.019	1.007	1.028	1.006
	(0.006)	(0.009)	(0.006)	(0.009)	(0.006)	(0.009)	(0.006)	(0.008)
385	0.959	1.021	0.957	1.020	0.958	1.022	0.974	1.008
	(0.054)	(0.089)	(0.054)	(0.090)	(0.054)	(0.089)	(0.054)	(0.089)
Scale			-0.018	-0.017	-0.018	-0.017	-0.009	-0.016
			(0.015)	(0.015)	(0.0147)	(0.015)	(0.015)	(0.015)
R&D					0.106	0.108	0.108	0.108
					(0.026)	(0.026)	(0.026)	(0.026)
d(H/N)							-0.121	-0.114
							(0.008)	(0.008)
RMSE	0.109	0.109	0.109	0.109	0.109	0.109	0.108	0.108
R^2	0.864	0.745	0.864	0.745	0.864	0.745	0.867	0.763
N	12558	12558	12558	12558	12558	12558	12558	12558

Standard deviations in parentheses. OLS and IV refer to estimation by OLS and instrumental variabel nethods. The row labeled 381 corresponds to the mark-up estimate in industry 381 etc.).

Table 3: Testing the stability of the parameter estimates on different subsamples

	1977-80		1981-85		Small plants		Medium plants		Large plants	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV
381	0.996	0.968	1.015	0.984	1.007	0.978	1.010	0.979	0.999	0.982
	(0.012)	(0.017)	(0.008)	(0.012)	(0.008)	(0.011)	(0.018)	(0.024)	(0.046)	(0.064)
382	1.007	1.011	0.990	0.988	0.996	0.991	0.999	1.033	0.994	0.999
	(0.011)	(0.017)	(0.009)	(0.016)	(0.009)	(0.014)	(0.016)	(0.030)	(0.017)	(0.024)
383	1.079	1.078	1.063	1.064	1.071	1.063	1.031	1.040	1.155	1.223
	(0.021)	(0.029)	(0.015)	(0.021)	(0.015)	(0.020)	(0.027)	(0.036)	(0.050)	(0.068)
384	1.015	1.009	1.036	1.004	1.027	0.996	1.035	1.038	1.019	0.974
	(0.010)	(0.014)	(0.007)	(0.010)	(0.008)	(0.012)	(0.010)	(0.013)	(0.016)	(0.023)
385	0.916	0.930	0.988	1.072	0.910	0.907	1.165	1.232	1.066	-0.917
	(0.098)	(0.152)	(0.064)	(0.107)	(0.066)	(0.114)	(0.101)	(0.137)	(0.349)	(2.116)
Scale	-0.014	-0.018	-0.003	-0.012	-0.005	-0.151	-0.011	-0.012	-0.042	-0.055
	(0.022)	(0.022)	(0.019)	(0.020)	(0.017)	(0.017)	(0.032)	(0.033)	(0.054)	(0.058)
R&D	0.106	0.109	0.109	0.108	0.176	0.175	0.105	0.110	0.083	0.082
	(0.094)	(0.095)	(0.026)	(0.026)	(0.057)	(0.057)	(0.029)	(0.030)	(0.069)	(0.071)
d(H/N)	-0.118	-0.113	-0.124	-0.115	-0.109	-0.098	-0.198	-0.198	-0.161	-0.127
	(0.012)	(0.012)	(0.010)	(0.011)	(0.009)	(0.009)	(0.021)	(0.021)	(0.036)	(0.048)
RMSE	0.111	0.111	0.106	0.106	0.111	0.111	0.098	0.099	0.099	0.102
R^2	0.845	0.730	0.881	0.786	0.856	0.741	0.889	0.815	0.910	0.848
N	5482	5482	7076	7076	9260	9260	2425	2425	873	873

(Standard deviations in parentheses. OLS and IV refer to estimation by OLS and instrumental variabel methods. The row labeled 381 corresponds to the mark-up estimate in industry 381 etc.).

Table 4: Introducing ownership variables

	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
381	1.008	0.978	1.008	0.978	1.008	0.978
	(0.007)	(0.010)	(0.007)	(0.010)	(0.007)	(0.010)
382	0.997	0.997	0.997	0.998	0.997	0.978
	(0.007)	(0.012)	(0.007)	(0.012)	(0.007)	(0.010)
383	1.069	1.070	1.069	1.069	1.070	1.070
	(0.012)	(0.017)	(0.012)	(0.017)	(0.012)	(0.017)
384	1.028	1.006	1.028	1.006	1.028	1.006
	(0.006)	(0.008)	(0.006)	(0.008)	(0.006)	(0.008)
385	0.974	1.008	0.977	1.012	0.974	1.008
	(0.054)	(0.089)	(0.054)	(0.089)	(0.054)	(0.089)
Scale	-0.009	-0.016	-0.009	-0.016	-0.009	-0.016
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
R&D	0.111	0.110	0.113	0.113	0.108	0.108
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
d(H/N)	-0.122	-0.114	-0.122	-0.114	-0.121	-0.114
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Foreign	-0.002	-0.002				
	(0.005)	(0.005)				
Public	-0.002	-0.002				
	(0.004)	(0.004)				
d(Dom.)			-0.015	-0.015		
			(0.010)	(0.010)		
d(For.)			-0.022	-0.022		
			(0.010)	(0.010)		
d(Privat)			-0.006	-0.007		
			(0.019)	(0.019)		
d(Public)			0.021	0.021		
			(0.015)	(0.015)		
Restruct.					0.001	0.001
					(0.004)	(0.004)
RMSE	0.108	0.108	0.108	0.108	0.108	0.108
R^2	0.867	0.764	0.867	0.764	0.867	0.764
N	12558	12558	12558	12558	12558	12558

(Standard deviations in parentheses. OLS and IV refer to estimation by OLS and instrumental variabel methods. The row labeled 381 corresponds to the mark-up estimate in industry 381 etc.). d(Dom.) refers to dummy variables reflecting a recent change in ownership from foreign to domestic, and vice versa for d(For.).)

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