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Lumpy Investments, Factor Adjustments and Productivity

Abstract:
This paper describes firms' output and factor demand before, during and after episodes of lumpy investments using a rich employer-employee panel data set for two manufacturing industries and one service industry. We focus on the simultaneous adjustment of capital, materials, man-hours, as well as the skill composition and hourly cost of labour. The investment spikes lead to roughly proportional changes in sales, labour and materials, while capital intensity increases significantly. Capital adjustments are found to be smoother in the service industry than in the two manufacturing industries, a difference that may be related to the labour intensity in the service industry. Finally, the changes in productivity associated with episodes of investment spikes are small, indicating that productivity improvements are related to learning-by-doing rather than instantaneous technological changes through investment spikes.

Keywords: Lumpy investments, Adjustment costs, Productivity, Panel data

JEL classification: C13, C33, D21, D24

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1. Introduction

Several studies have pointed out that firms adjust productive input factors (e.g. capital and labour) in a lumpy fashion.[1] Such a pattern may reflect that smooth adjustment of capital and labour is precluded by fixed costs, (partial) irreversibilities or indivisibilities. Moreover, Power (1998), Huggett and Opsina (2001) and Sakellaris (2004) find that the immediate impact of large investments on productivity is negative. This finding may reflect adjustment costs due to disruption of production, e.g. temporary closure of shops during renovation of buildings.

The lumpy nature of capital and labour adjustments may be related to dynamic interrelatedness between the adjustments of different factors. The literature described in footnote 1 investigates the adjustment of capital and labour separately. However, as pointed out by Abel and Eberly (1998), lumpiness in employment patterns may be due to interrelatedness between different production factors, rather than a fixed cost component of labour adjustment.[2]

The objective of this paper is to use a new and, to our knowledge, unique matched employer-employee data set from Norway, based on five various registers, to describe changes in factor demand, productivity and the skill composition of the labour stock before, during, and after episodes of investment spikes. In the tradition of Power (1998), Sakellaris (2004) and others our analysis is mainly explorative. We focus on three types of factor inputs: capital, materials and man-hours. Our analysis will focus on how lumpiness in one factor (equipment capital) affects the dynamics of the whole system of supply and factor use. We analyse two manufacturing industries and one service industry over the period 1995-2003.

The existing literature has focused mainly on the manufacturing sector. One novelty of our study is that we are able to describe the link between investments, factor adjustments and productivity also for services, which is a much more labour intensive sector. Another advantage of our data is that we have a comprehensive sample of firms, consisting of all joint stock (i.e., limited dependent) companies in the industries we consider. Thus, our data include both large, medium-sized and small firms (with as few as 1 employee).

In the literature a lumpy investment is identified as an investment-to-capital ratio larger than a certain threshold, typically 20 per cent, see Cooper, Haltiwanger and Power (1999). However, we need

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[1] For capital adjustment see Caballero, Engel and Haltiwanger (1997), Doms and Dunne (1998), Barnett and Sakellaris (1998), Cooper, Haltiwanger and Power (1999), and Abel and Eberly (2002) for the US, Nilsen and Schiantarelli (2003) for Norway, and Letterie and Pfann (2005) for the Netherlands. For labour adjustment see the seminal contributions by Hamermesh (1989, 1992, 1995), and the more recent ones by Bentolila and Saint-Paul (1994), Rota (1995), Abowd and Kramarz (2003), Campbell and Fisher (2000, 2004), Goux, Maurin and Pauchet (2001) and Nilsen, Salvanes and Schiantarelli (2003).

[2] See Nadiri and Rosen (1969) for an early study of interrelated factor demand.

to take into account that investment ratios above 20 per cent occurs frequently among small firms, as the variance of the investment ratio decreases significantly with firm size. To address this problem, we modify the threshold so that it depends on the variance of the investment ratio *conditional on size*. In our implementation the threshold for being an investment spike decreases with the size of the firm.

The variables of interest in this analysis comprise sales, materials, hourly wage costs, share of man-hours worked by high-skilled persons, the capital stock and total man-hours. To analyse the dynamics of these variables in the periods preceding and following an investment spike, we define four dummy variables indicating (i) the period before the spike, (ii) the year in which the spike takes place, (iii) the year following the spike, and finally (iv) the period consisting of two or more years subsequent to the spike. By using a random effects model where all the response variables are modelled simultaneously, we are able to obtain efficient estimators using the method of maximum likelihood.

In summary, we find that investments are lumpy, indicating that firms concentrate their investments into short periods of time. This is consistent with the existence of non-convexities in the adjustment cost function for capital[3], caused by either fixed adjustment costs or indivisibilities. Evidence suggests that the adjustment costs for capital is smoother in the service industry than in the two manufacturing industries. In all industries, an investment spike leads to approximately proportional changes in sales, man-hours and materials after 2-3 years, while the capital intensity increases significantly. Finally, our findings indicate that the changes in productivity associated with episodes of investment spikes are small, so that productivity improvements may be related to learning-by-doing, rather than instantaneous technological changes through investment spikes.
The paper proceeds as follows. In Section 2 we describe the data and define the variables together with some descriptive statistics. Section 3 presents the empirical specification adopted. Section 4 discusses the results. Finally, Section 5 concludes the paper.

2. Data description

2.1 The data sources

We have constructed panel data sets for Norwegian firms in three industries, covering the period 1995-2003. The three industries are Manufacture of machinery and equipment (NACE 29), Manufacture of electrical and optical equipment (NACE 30-33) and Retail trade/repair of personal and household goods (NACE 52). The first industry is a traditional manufacturing industry, the second is a high-tech

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[3] See Hamermesh and Pfann (1996) for a critical review about adjustment cost functions.

industry and the last one is a service industry. From now on we refer to the three industries as Machinery, Electrical equipment and Retail trade, respectively. The empirical analysis is carried out at the firm level, where accounting information is available.

Five different sources of Norwegian microdata are used. Two of them are firm level data sets. One is based on the accounts statistics for joint stock companies and the other one is the structural statistics for the different industrial activities. The three remaining data sets are individual level data. These are The Register of Employers and Employees (REE), The Pay Statements Register (PSR), and The National Education Database (NED). All data are annual. The individual level data were organized in a common database and then aggregated to the firm level.

Table 1. Number of firms in the final sample

Year	Machinery	Electrical equipment	Retail trade
1996	500	300	6,958
1997	531	336	7,618
1998	538	347	7,893
1999	544	344	8,039
2000	548	353	8,026
2001	567	367	8,122
2002	560	378	8,108
Total number	883	577	12,661

After aggregation of the individual level variables to the firm level, we obtain an unbalanced panel data sets for 1,743 firms in Machinery, with approximately 900 observations per year; 1,177 firms in Electrical equipment, with approximately 600 observations per year, and 22,806 firms in Retail trade, with approximately 11,500 observations per year in 1995-2003. The model used in the paper contains one lag and one lead. This entails the loss of observations in the first and last year. Moreover, only firms with at least 3 years of contiguous data and non-missing variables were retained. As one can see from Table 1 the size of the final samples have been considerably reduced.

2.2 Variable construction

Both accounts statistics and structural statistics distinguish between several groups of physical assets. In order to obtain consistent definitions of asset categories for the two statistics sources and over the whole observation period, all assets have been divided into two types: Buildings and land, b; and Other tangible fixed assets, e. Group e consists of equipment capital, such as machinery, vehicles, tools, furniture, transport equipment, etc. The expected lifetimes of the physical assets in group b are considerably longer than in group e, respectively about 40-60 and 3-10 years. Table 2 gives an overview of the variables used in the empirical analysis and the data sources used to construct them.

Table 2. Overview of variables and data sources

Variable	Interpretation	Data source(s)
s	log of sale[a]	accounts statistics
m	log of materials[a]	accounts statistics
mh	log of man-hours[b]	REE
w	log of hourly labour costs[a,b]	REE, PSR, accounts statistics
ssk	share of man-hours worked by skilled persons[b]	REE, PSR, NED
K^j	capital stock[c] of type j, $j \in \{b,e\}$	accounts statistics, structural statistics
I^j	acquisitions of capital[a] of type j, $j \in \{b,e\}$	structural statistics
Derived	variables:	
k	log of total capital, K	
lp	log of labour productivity: $s - mh$	
ki	log of capital intensity: $k - mh$	
mi	log of materials intensity: $m - mh$	
S	Investment spike indicator	

[a] Deflated by the official consumer price index.
[b] Man-hours according to labour contracts.
[c] Capital stock at the end of the year.

The logarithm of sales, s, is defined as the logarithm of operating revenues, which are available at the firm level from the accounts statistics. Input of materials, cf. m, is obtained from the accounts statistics and is computed as operating expenses less payroll expenses, depreciation, write-downs and operational leasing.

The logarithm of man-hours, mh, is calculated as the logarithm of the sum of all individual man-hours worked by employees in the given firm according to the contract. Then the logarithm of hourly labour costs, w, is the logarithm of the sum of all recorded labour costs in the firm, including wages, bonuses and commissions, payroll taxes, etc., minus the logarithm of man-hours, mh. The share of man-hours worked by skilled persons, ssk, was calculated on the basis of the individual data sets REE, PSR og NED. For each industry we distinguish between two educational groups, high-skilled and low-skilled. As high-skilled workers we define those who have post-secondary education, i.e., persons that have studied for at least 13 years (for the description of the educational levels see Table A1). The man-hours worked by skilled persons were aggregated to the firm level and divided by the total number of man-hours worked for the given firm.

We distinguish between two types of capital, building capital, K_{it}^b, and equipment capital, K_{it}^e. Investments data for the two capital types, I_{it}^b and I_{it}^e, are taken from the structural statistics. We define as an investment any acquisition of a fixed capital good (new or used), which is capitalized, i.e., taken into the firm's balance sheet, and depreciated over its expected lifetime. Repairs are considered as operating costs, unless it brings the asset to a higher standard so that the value of the asset is increased relative to its ex ante expected value. In the latter case, the increased value is an investment (see the discussion in McGratten and Schmitz, 1999).

Sometimes the firm does not buy the asset, but pays leasing costs. There are two types of leasing: operational and financial. With an operational leasing agreement, the firm that leases an asset does not capitalize it in its balance sheet, but pays leasing costs, e.g. rents on buildings. Financial leasing means that most of the risks and rewards are transferred to the firm that leases the tangible fixed asset. In this case the firm that leases the asset capitalize it. Hence, financial leasing is an investment.

Total capital, K_{it}, is an aggregate of K_{it}^b and K_{it}^e. We follow the practice of most official statistical agencies, e.g. Bureau of Labor Statistics, and use a Törnqvist volume index with common weights across firms within the same industry at the same period of time (see OECD, 2001). The Törnqvist index can be interpreted as a constant returns to scale Cobb-Douglas aggregation function, where the elasticity of each of the two types of capital is estimated from their share of total (annualized) cost of capital.[4] An important property of the Törnqvist volume index of capital is that it can be equivalently formulated in terms of the rental cost of capital.[5] Thus it is straightforward to aggregate capital owned by the firm and capital obtained by operational leasing. Both types of capital are included in K_{it}^j, for $j \in \{b, e\}$.

The main idea of the paper is to estimate the effects of investment shocks on some key variables. For this purpose we identify investment spikes, S_{it}. An investment spike must be defined so as to capture sudden and unusual burst in investment activity of the firm. In accordance with the literature, we define investment spikes only for equipment capital, K_{it}^e.[6] Traditionally, the concept of a

[4] The aggregate capital stock is calculated as $K_{it} = \left(K_{it}^b\right)^{v_t} \left(K_{it}^e\right)^{1-v_t}$, where $v_t = \sum_i R_{it}^b / \sum_i (R_{it}^b + R_{it}^e)$ and, for $j \in \{b, e\}$, $R_{it}^j = (r + \delta_j) K_{it}^j$. Thus R_{it}^j is the annualised cost of capital. Median depreciation rates, δ_j, are obtained from the accounts statistics, see Raknerud, Rønningen and Skjerpen (2003), while r is the real rate of return, which we calculated from the average real return on 10-year government bonds in the period 1996-2002, i.e. 4.2 per cent.

[5] That is, $\ln K_{it} = v_t \ln R_{it}^b + (1 - v_t) \ln R_{it}^e$ + constant.

[6] This is not to deny that spikes in building capital may be interesting for some purposes, e.g. in productivity analysis. For example, in Retail trade, the capacity and location of shops and inventories may affect both sales and variable factor costs (e.g. transportation costs) and thus productivity.

spike has been implemented in mainly two ways: either the equipment investment-to-equipment capital ratio $I_{it}^{e}/K_{i,t-1}^{e}$ (hereafter *investment ratio*, for short) should be larger than 0.2, denoted absolute spike (see Cooper, Haltwanger and Power, 1999), or $I_{it}^{e}/K_{i,t-1}^{e}$ should exceed the median investment ratio for firm *i* by a factor of ρ, which is typically chosen in the range from 1.5 to 3 (see Power, 1998). That is,

$$I_{it}^{e} / K_{i,t-1}^{e} > \rho \ \text{median}_i \left(I_{it}^{e} / K_{i,t-1}^{e} \right),$$

denoted a relative spike.The international literature focuses mostly on large firms. However, as noted above, our data set is more comprehensive and comprises a large share of small and medium-sized firms. This raises some special problems, which need to be addressed before operationalizing the concept of an investment spike.

We find it reasonable to require that an investment spike must fulfil three criteria: (i) it must be a large investment in relative terms; both relative to the investment history of the firm and relative to the dispersion in the distribution of the investment ratios in the population as a whole, (ii) it must be a rare event, and (iii) the spike must account for a disproportional share of total investments (at the industry level). In view of these criteria, we consider the following modified definition of a spike:

$$I_{it}^{e} / K_{i,t-1}^{e} > \max\ [\alpha\sigma(K_{i,t-1}^{e}), 0.20],$$

where α is a fixed parameter and $\sigma\left(K_{t-1}^{e}\right)$ expresses the expected absolute deviation of $I_{it}^{e} / K_{i,t-1}^{e}$ from its global mean, ξ, as a function of $K_{i,t-1}^{e}$.

The first argument in the max operator takes into account that there are larger fluctuations in the investment ratios of small firms than of large firms. That is, $\sigma\left(K_{i,t-1}^{e}\right)$ is a decreasing function of $K_{i,t-1}^{e}$. If one uses the criterion employed by Power (1998) on the Norwegian data, one obtains a disproportionate number of spikes for small firms, but these spikes would not be unusual events and account for an insignificant share of total investments. On the other hand, for a fixed value of α, there will exist a value $K^{*e}_{i,t-1}$ such that for $K_{i,t-1}^{e} > K^{*e}_{i,t-1}$, the second argument of the max operator is binding. Thus, for sufficiently large firms, the criterion will coincide with the criterion of a 20 per cent investment ratio[7]. In the subsequent section we will give a parametric representation of the σ -function and explain how it is estimated.

A comparison of our combined rule with Power's relative rule, for different values of α and ρ is presented in Table 3. We see that our (heteroscedasticity adjusted) rule gives a surprisingly similar pattern as found by Power (1998). On the other hand, the absolute spike criterion $(\alpha = 0)$ does not give credible results.

Table 3. Comparing different rules for identifying investment spikes

Power's relative rule. American data			Our combined rule. Norwegian data		
ρ	Share of # observations	Share of total investment	α	Share of # observations	Share of total investment
			0	22	39
1.75	14	46	1.75	9	35
2.50	8	31	2.50	5	30
3.25	5	26	3.25	4	27

As explained above, a firm undergoes an investment spike in year *t*, i.e. $S_{it} = 1$, if its equipment investment ratio exceeds $\max\left[\alpha\sigma\left(K_{i,t-1}^{e}\right), 0.20\right]$. Formally,

$$S_{it} = \begin{cases} 1 & \text{if } I_{it}^{e} / K_{i,t-1}^{e} > \max\left[\alpha\sigma\left(K_{i,t-1}^{e}\right), 0.20\right] \\ 0 & \text{else} \end{cases} ,$$

where $\sigma\left(K_{i,t-1}^{e}\right) \equiv E\left(\left|\left(I_{it}^{e} / K_{i,t-1}^{e}\right) - \xi\right|\right)$ is the expected absolute deviation of the investment ratio as a function of the equipment capital stock, with $\xi \equiv E\left(I_{it}^{e} / K_{i,t-1}^{e}\right)$. That is, ξ is the (industry specific) unconditional mean investment ratio for equipment capital.

We model $\sigma\left(K_{i,t-1}^{e}\right)$ as a generalized Box-Cox transformation of equipment capital:

$$\sigma\left(K_{i,t-1}^{e}\right) = \gamma_0 + \gamma_1 \frac{\left(K_{i,t-1}^{e} + \eta\right)^{\lambda} - 1}{\lambda} .$$

[7] Note that in the special case with $\alpha = 0$, our modified rule is identical to the absolute spike criterion.

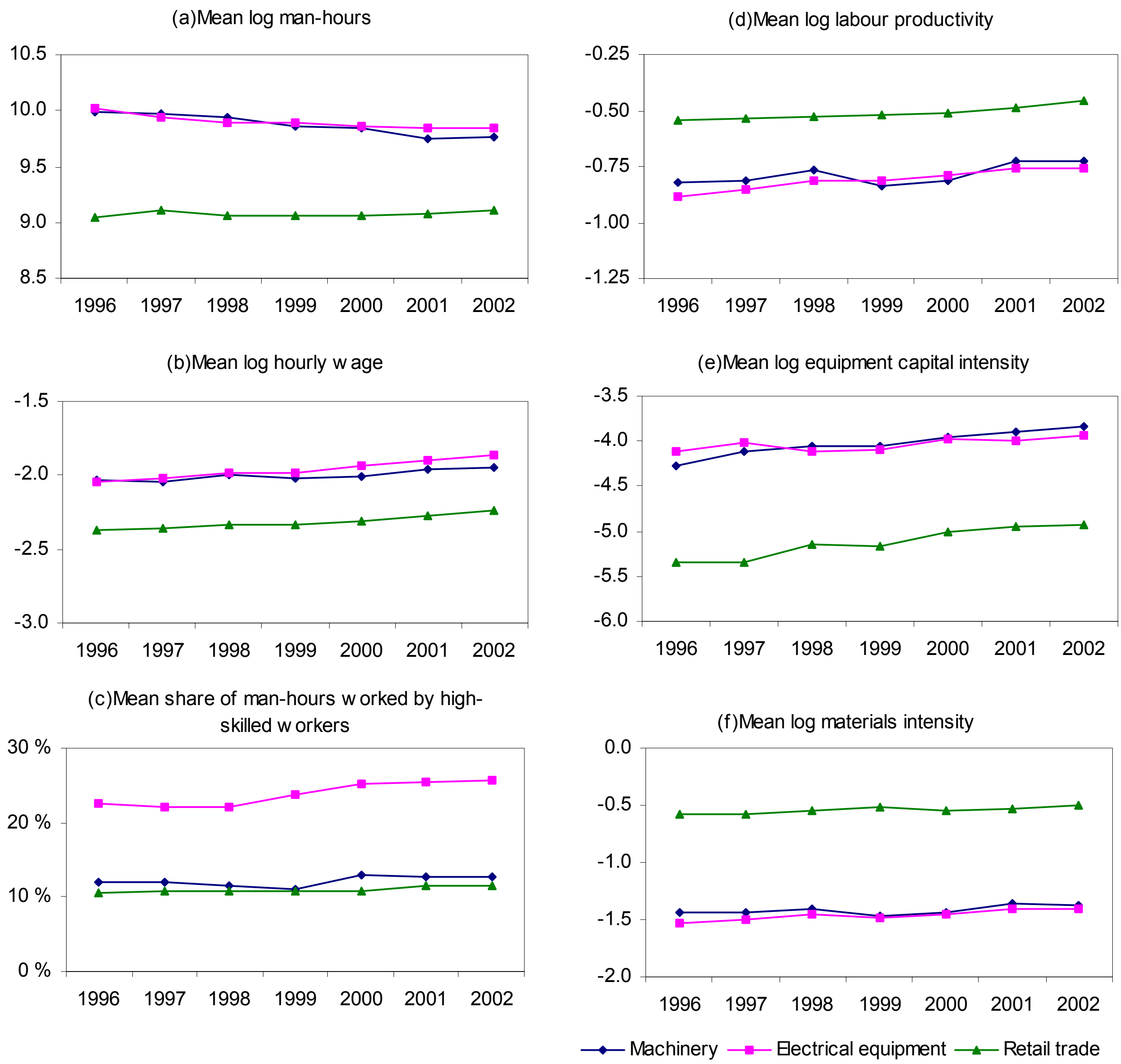
When estimating this regression function, we use the method of non-linear least squares with $\left|I_{it}^{e} / K_{i,t-1}^{e} - \hat{\xi}\right|$ as the left-hand variable, where $\hat{\xi}$ is the empirical mean of the investment ratio. We find a clear pattern: the estimate of γ_1 is negative in all industries, between -.18 (in Machinery) and -.08 (in Electrical equipment), and highly significant (standard errors are less than .004). Thus, there is a strong negative relation between the absolute deviation of the investment ratio of the firm and its capital stock (at the beginning of the year). That is, the fluctuations in the investment ratios of small firms are much larger than for large firms. Furthermore, we find that the estimates of λ and η are close to zero, which corresponds to a log-linear model in $K_{i,t-1}^{e}$. Our combined rule for identifying investment spikes with $\alpha = 1.75$ classifies about 10 per cent of the observations as spikes, accounting for 1/3 of total investments. The 20 per cent threshold was binding for 4-6 per cent of these spikes. All our results are robust with respect to variations in α within the range from 1.75 to 3.25 (cf. Table 3).

2.3 Descriptive statistics

The panels of Figure 1 display the dynamic behaviour of the mean of the constructed variables in different industries. We notice that the two manufacturing industries are represented in average by larger firms (in terms of man-hours) than the Retail trade industry.[8] The average hourly wage in the former is higher than in the latter, but the growth rate of average hourly wage is nearly the same in all the three industries (panels (a) and (b)). Electrical equipment can be characterized as a high-tech industry, where the knowledge of workers is of particular importance. As we can see, the share of man-hours worked by high-skilled workers in Electrical equipments is more than twice as high as in the two other industries (panel (c)), emphasizing the high-tech profile of this industry. However, the share of man-hours worked by high-skilled workers does not change much during 1996-2002 in any of the three industries. It grows slowly in Electrical equipment and shows little variation in the two other industries.

[8] Similar differences are found when we measure size with regard to capital.

Figure 1. The mean of variables in different industries over time



Labour productivity, i.e., sales per man-hour, generally grows during the years 1996-2002 (panel (d)). We see that labour productivity is much higher in Retail trade than in the two manufacturing industries. This is an effect of the much higher material intensity in Retail trade and does, of course, not mean the productive contribution of each man-hour is higher in Retail trade. Clearly, sales are an inappropriate output measure for productivity comparisons across industries with different material intensities. Also notice that the two manufacturing industries are more equipment capital-intensive than Retail trade, but much less materials-intensive (panels (e) and (f)). Whereas the growth rate of average capital intensity in Machinery and Retail trade are almost identical, it is lower for Electrical equipment.

Panel (a) of Fig. 2 shows operational leasing costs as a share of total (annualized) costs of capital. We can see that operational leasing contributes significantly to the capital input in Norwegian firms. In the two manufacturing industries, operational leasing costs constituted around 40 per cent of the total costs of buildings and land in 1996, increasing to 60-70 per cent in 2002. In Retail trade this share is over 90 per cent during the whole period. Also for equipment capital, operational leasing costs represent a substantial share of the costs of capital. For example, in 1996 this share was around 40 per cent in both manufacturing industries and about 30 per cent in Retail trade. Overall, Fig. 2, panel (a), shows why leasing must be included in any adequate capital input measure, regardless of whether the focus is on equipment capital or aggregate total capital. In particular, leasing contributes to a substantial smoothing of capital adjustments. This is confirmed from the distribution of firm-level growth rates of capital from one year to the next (not shown), which is much less skewed to the right than if (operational) leasing were excluded from the capital measure, as e.g. in Carlsson and Laséen (2005).

Panel (b) of Fig. 2 shows the investment ratio for equipment capital at the industry level. In each of the three industries the firms invested more intensively at the beginning of the period than at the end. This may be influenced by the ending of the recession around 1993-1994, where firms had low capital stocks after many years of low investment activity. When capital stocks increased at the firm level, investment ratios started to fall. Panel (c) of Fig. 2 shows the share of investment observations classified as investment spikes according to our criterion. We see the same decreasing pattern as for the investment ratios in panel (b) – 8-13 per cent of the firms experienced an investment spike in 1996 against 5-7 per cent in 2002. In general, as many as 30 per cent of the firms in each industry have experienced at least one spike during the period 1996-2002.

Figure 2. Operational leasing, investment ratios and relative frequency of spikes

3. Methodology

We are interested in the performance of firms measured by a vector of response variables, X_{it}. Specifically, we want to study how X_{it} evolves over time; prior to, during and after the occurrence of an investment spike.

Let us first define a vector of covariates, which identifies the position of the firm in a "window" of observations around the spike. Let T_i^{start} and T_i^{end} denote the first and last year firm *i* occurs in the sample. We define

$$Z_{it} = \begin{bmatrix} Z_{1,it} \\ Z_{2,it} \\ Z_{3,it} \\ Z_{4,it} \end{bmatrix} = \begin{bmatrix} max_{T_i^{start} \le s \le T_i^{end}} S_{is} \\ S_{it} \\ (1-S_{it})S_{i,t-1} \\ (1-S_{it})(1-S_{i,t-1})\, max_{s \le t-2}\, S_{is} \end{bmatrix}.$$

The first component of Z_{it}, $Z_{1,it}$, is an indicator of whether the firm experiences at least one investment spike during the whole period $\left[T_i^{start}, T_i^{end}\right]$. The second component, $Z_{2,it}$, is an indicator of a spike in year *t*, while the third component, $Z_{3,it}$, is an indicator of a spike in year $t-1$ but not in *t*. Finally, $Z_{4,it}$ is an indicator that there was an investment spike during $\left[T_i^{start}, t-2\right]$ but not in year t or $t-1$. This last covariate is used to identify possible shifts in the average level of X_{it} after the spike, compared to its normal level prior to the spike.

The response variables we consider are contained in a vector X_{it} as follows:

$$X_{it} = (s_{it}, m_{it}, w_{it}, ssk_{it}, k_{it}, mh_{it})'.$$

We want to investigate the co-movements of X_{it} as a function of the covariates, Z_{it}. For this purpose we choose a simple random effects model:

$$X_{it} = u_i + \mu_t + \sum_{k=1}^{4} \beta_k Z_{k,it} + e_{it},\ t = T_i^{start}, T_i^{start}+1, \ldots, T_i^{end},$$

where u_i is a 6x1 vector of random effects, with mean zero and unrestricted covariance matrix, μ_t is a vector of time-specific intercepts common to all firms in the industry, $\beta_1, .., \beta_4$ are four 6x1 vectors of regression parameters describing the relation between X_{it} and $Z_{1,it}$, $Z_{2,it}$, $Z_{3,it}$ and $Z_{4,it}$ and, finally,

e_{it} is a vector of idiosyncratic error terms. The model is estimated separately for each of the three industries by the method of maximum likelihood, using a computer algorithm which we have written in GAUSS.

Following Power (1998), Sakellaris (2004) and Letterie, Pfann and Polder (2004), our approach is mainly explorative. Our model provides a useful statistical description of the data, but cannot be directly interpreted in terms of causal relationships. For example, one cannot interpret Z_{it} as exogenous and X_{it} as endogenous in a theoretical sense.

Our model has some apparent similarities to Sakellaris (2004), but also some differences. For instance, we do not estimate an equation for each of the interest variables in X_{it} separately, but set up all the equations simultaneously in a Seemingly Unrelated Regression Equations (SURE) system. This will lead to more efficient estimation, as we utilize the cross-correlation structure across the latent variable, i.e., u_i and e_{it}, cf. Avery (1977) and Baltagi (1980) who address this issue within a feasible GLS framework for the balanced case.

For the group of firms that never experiences spikes, the pattern of X_{it} over time has a simple two-way structure, where each firm randomly fluctuates around $u_i + \mu_t$. The movement of the firms in this group over time is entirely determined by μ_t. On the other hand, firms that experience spikes may be systematically different from the other firms, both before, during and after the spike.

Prior to the spike, the average level of X_{it} equals $\mu_t + \beta_1$. We can interpret β_1 as the expected difference in the level of X_{it} between a firm with a spike *just prior to the spike occurs* and a firm with no spike. The event of a spike is here restricted to the observation period 1995-2003. Since the concept of a spike is (also) meant to capture a large part of aggregate investments by a relatively few investment episodes, we may expect a disproportional representation of large firms among the firms with spikes.

If a spike occurs in year *t*, this is accompanied by a shift in X_{it} equal to β_2 compared to the years before the spike. If *t* is the year just after a spike, the shift equals β_3. Finally, the impact of the spike in any later year is β_4. Thus, β_4 is the long-run effect on X_{it} of the spike, compared to its normal level before the spike.

4. Results

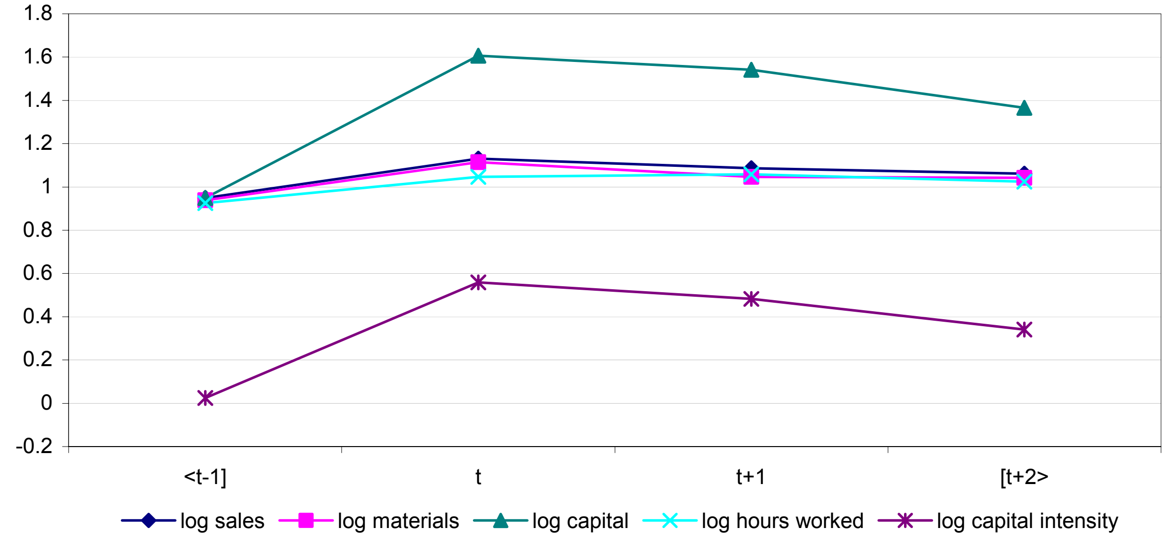
In this section we comment upon our empirical findings. Table 4 gives the estimated values of the parameters β_k for Machinery, Electrical equipment and Retail trade from the model described in the previous section. We will use the notation $\beta_{k,j}$ to refer to the j'th component of β_k, e.g. $\beta_{k,1}$ denotes the sales-component, $\beta_{k,2}$ denotes the man-hours component, etc. Furthermore, $\hat{\beta}_k$ denotes the maximum likelihood estimator of β_k.

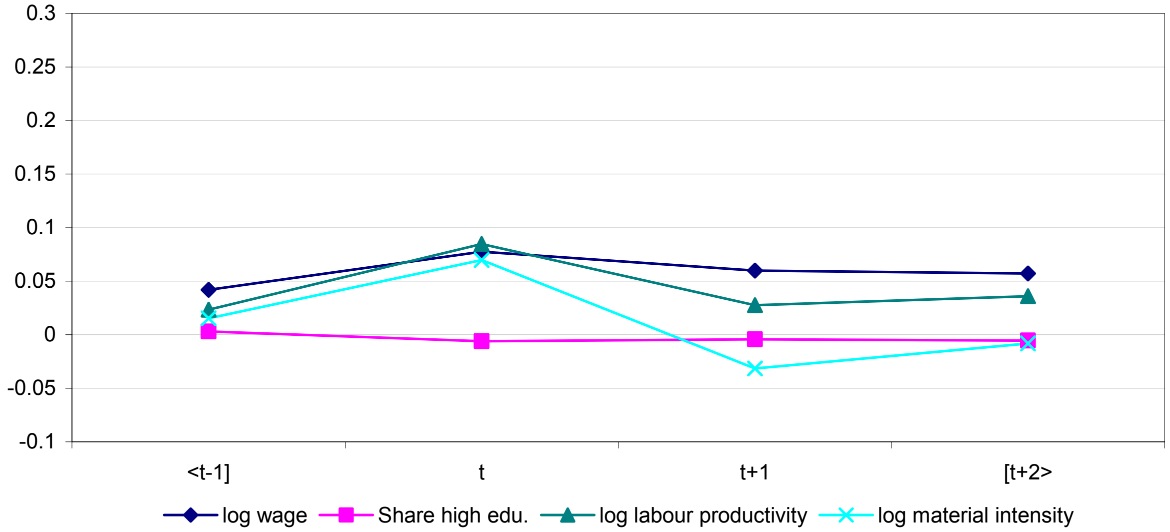
Table 4. Estimate of the β_k parameters

	Parameters estsimates (standard errors)			
	β_1	β_2	β_3	β_4
Machinery				
s	0.90 (.10)	0.17 (.02)	0.13 (.03)	0.12 (.03)
m	0.89 (.11)	0.16 (.03)	0.10 (.03)	0.10 (.03)
w	0.04 (.02)	0.03 (.01)	0.01 (.02)	0.00 (.02)
ssk	0.00 (.01)	0.01 (.00)	-0.01 (.01)	-0.01 (.01)
k	0.90 (.10)	0.53 (.04)	0.46 (.04)	0.30 (.05)
mh	0.87 (.10)	0.11 (.02)	0.15 (.02)	0.12 (.02)
Electrical equipment				
s	0.67 (.14)	0.22 (.03)	0.24 (.03)	0.21 (.03)
m	0.70 (.15)	0.23 (.03)	0.27 (.04)	0.23 (.04)
w	0.04 (.03)	0.04 (.02)	0.02 (.02)	0.02 (.02)
ssk	0.02 (.02)	0.01 (.01)	0.00 (.01)	0.01 (.01)
k	0.56 (.14)	0.40 (.05)	0.38 (.05)	0.34 (.06)
mh	0.58 (.12)	0.12 (.02)	0.19 (.03)	0.17 (.03)
Retail trade				
s	0.73 (.07)	0.08 (.01)	0.10 (.02)	0.08 (.02)
m	0.73 (.07)	0.08 (.01)	0.09 (.02)	0.06 (.02)
w	0.10 (.02)	0.04 (.02)	0.08 (.01)	0.03 (.02)
ssk	-0.02 (.01)	0.01 (.01)	0.01 (.01)	0.02 (.01)
k	0.64 (.07)	0.29 (.03)	0.32 (.03)	0.28 (.03)
mh	0.52 (.06)	0.06 (.02)	0.05 (.02)	0.07 (.02)

The corresponding figures 3, 4 and 5 illustrate the results from Table 4 showing the development in firm characteristics before, during and after the occurrence of an investment spike for a representative firm. On the vertical axis we graph the average difference between firms without spikes and firms with spikes over a sequence of 4 periods where, on the horizontal axis, $< t-1]$ represents all years before the spike, *t* represents the year in which the spike takes place, $t+1$ is the year following the spike, and $[t+2 >$ corresponds to the interval of two or more years subsequent to the spike. The vertical axis shows the level of the graphs over these four periods, i.e. β_1, $\beta_1+\beta_2$, $\beta_1+\beta_3$ and $\beta_1+\beta_4$, respectively.

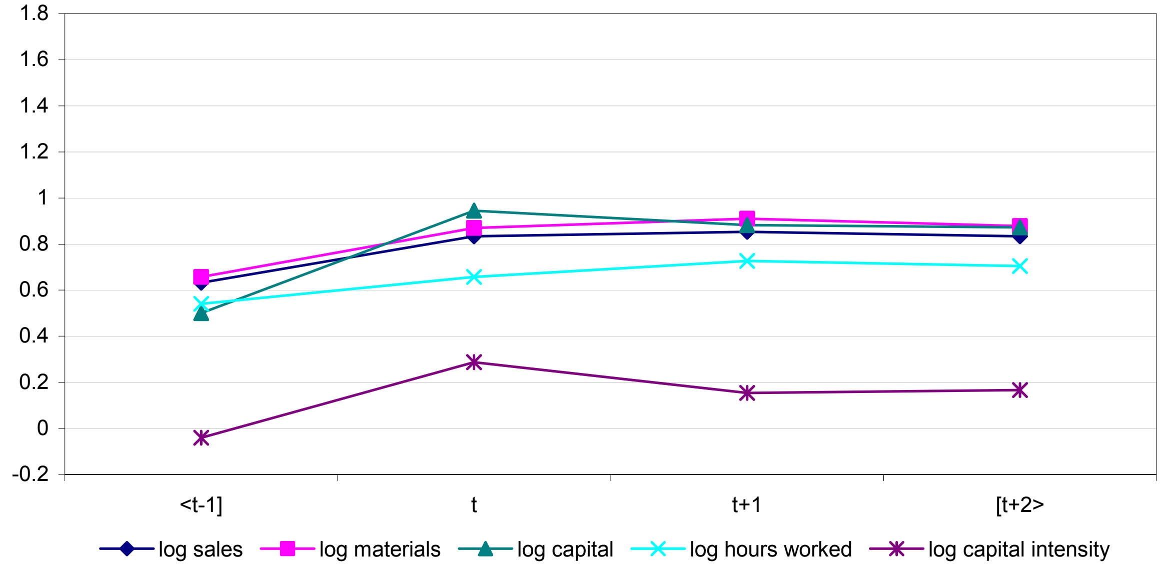
Figure 3: Machinery. Firm characteristics before, during and after an investment spike. Measured as deviations from firms without spikes

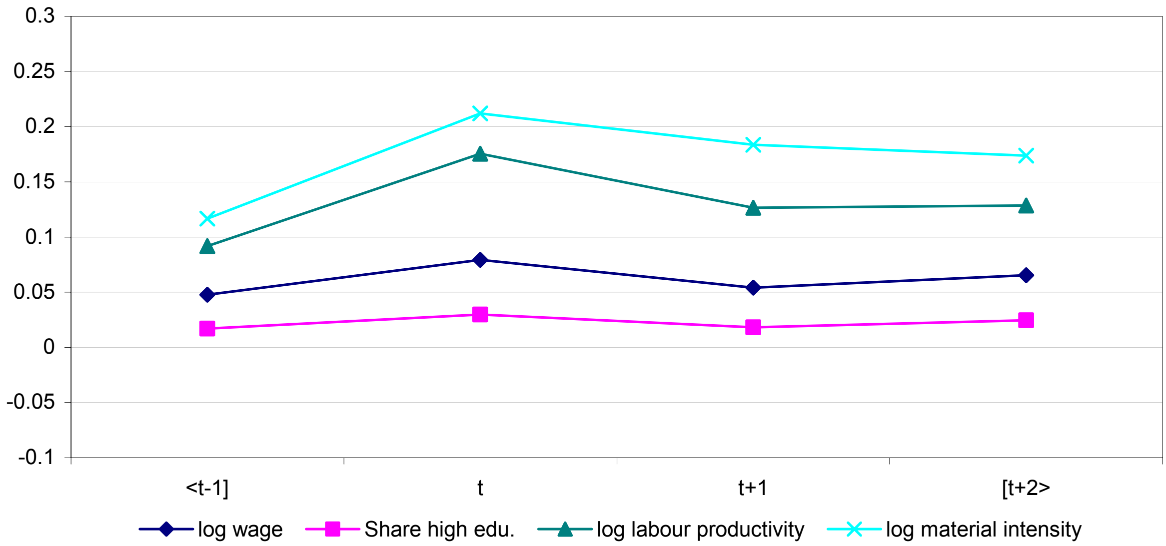




In addition, we depict the development in three derived measures of firm characteristics: labour productivity, $s-mh$, capital intensity, $k-mh$, and materials intensity, $m-mh$. Our approach allows for persistent effects of the investment spikes, since β_4 may be different from a vector of zeros. In contrast, Sakellaris (2004) forces the effects of a lumpy investment (in year t) to vanish by year $t+2$.

Figure 4: Electrical equipment. Firm characteristics before, during and after an investment spike. Measured as deviations from firms without spikes

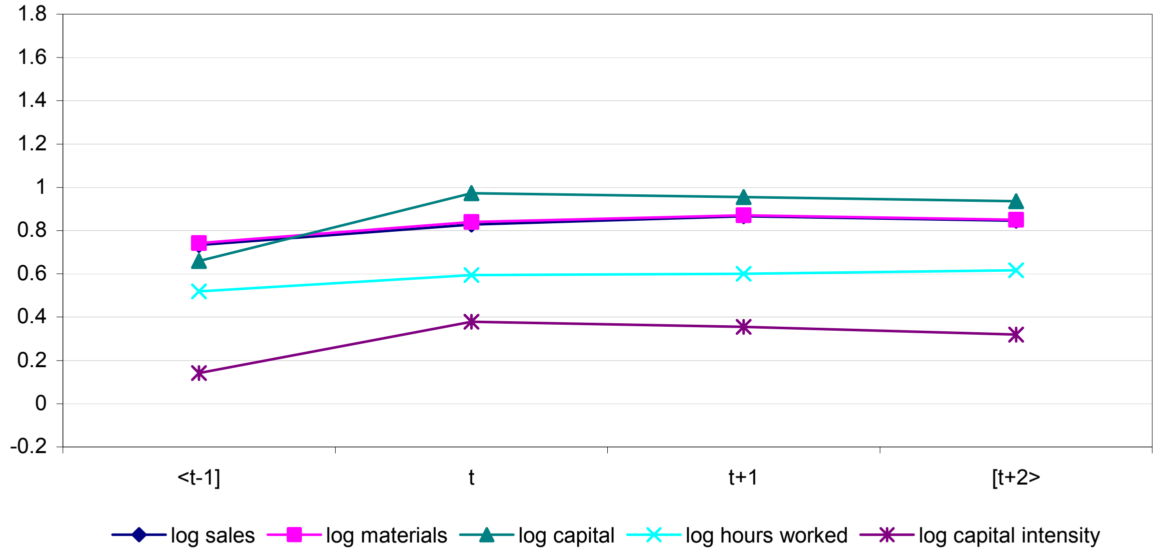


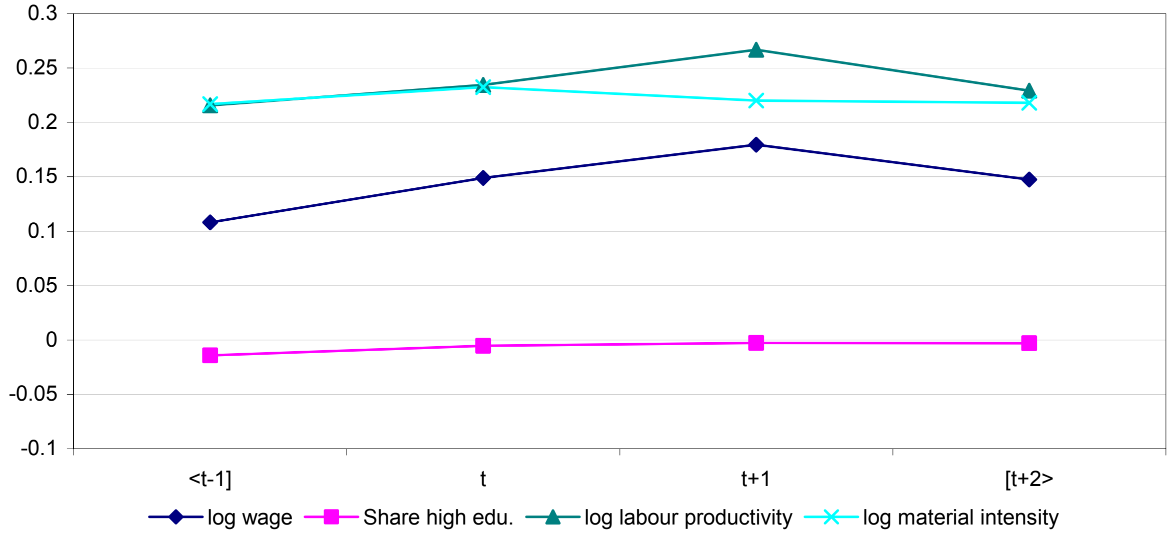


In all three industries the firms that experience one or more spikes are in general larger than firms without spikes: their (log) sales, (log) man-hours and (log) stock of capital are significantly higher than for firms without any spikes. This could be due to our definition of a spike, requiring the threshold of spikes to be larger for smaller firms.[9]

[9] Nilsen and Schiantarelli (2003) found significant differences in the investment pattern between small and large firms and plants, with more frequent episodes of inactivity and lumpier investment for smaller units.

Figure 5: Retail trade. Firm characteristics before, during and after an investment spike. Measured as deviations from firms without spikes





Focusing first on capital, we see from the estimate of β_2 for Machinery that the relative growth in capital from *t*-1 to *t* is .53. For Electrical equipment and Retail trade, the corresponding estimates are .40 and .29, respectively. We know from Table 3 that those episodes of spikes count for 35 per cent of the total investments in the sample.

A pattern where investments are lumpy indicates that firms concentrate their investments in short periods of time. This is consistent with the existence of non-convex adjustment costs for capital caused by either fixed adjustment costs or indivisibilities. That the estimates of the β_2-components corresponding to *s, m, k* and *mh* are significantly lower for Retail trade than for the manufacturing industries, indicates that the importance of non-convexities of the adjustment costs is lower in Retail trade.

The effects of an investment spike in the year after the spike is picked up by β_3. We generally find that $\hat{\beta}_3$ is similar to $\hat{\beta}_2$. In Machinery the estimated change in the capital stock from *t* to *t*+1 is negative, i.e., $\hat{\beta}_{3,5} < \hat{\beta}_{2,5}$, but moderate. In the other industries the effect of the spike is virtually the same in *t* and *t*+1. This is also what Sakellaris (2004) finds, i.e., that lumpy capital adjustments are followed by smooth adjustments. With regard to cross-industry comparisons, the pattern of $\hat{\beta}_3$ is similar to that of $\hat{\beta}_2$: the estimate of $\beta_{3,5}$ is smaller in Retail trade (.32) than in Machinery and Electrical equipment (.46 and .38, respectively).

The relative changes in the capital stock from year $t-1$ (just prior to the spike) to $[t+2>$ (two or more years after the spike), is positive and highly significant for all the three industries, as seen from the estimates of β_4. This means that the capital stock stays at a new and higher level after the investment episodes. Moreover, the effect is similar in all the industries. The estimates of the capital coefficient $\beta_{4,5}$ in Machinery, Electrical equipment and Retail trade are .30, .34 and .28, respectively. Turning to sales, we find that the increase in log sales from period *t*-1 to *t* is .17, .22, and .08 in Machinery, Electrical equipment and Retail trade, respectively. From the estimates of β_4 in Table 4 we see that two or more years after the spike, the relative increase in sales is about 10 per cent in Machinery and Retail trade, and about 20 per cent in Electrical equipment. Thus the growth rate of the capital stock is higher than for sales, indicating that non-convexities in the adjustment costs of capital are present. Moreover, the effect on sales is significantly larger for Electrical equipment than for the other two industries.

The growth patterns of materials and man-hours are very similar to that of sales. That is, the changes in sales, man-hours and materials are almost proportional, with a much higher growth rate in Electrical equipment (about 20 per cent two or more years after the spike) than in the other industries (about 10 per cent). This may indicate that changes in labour are as costless as for materials and much easier to carry through than changes in the capital stock. The increase in man-hours and materials during the investment spike episodes may be induced by interrelatedness between different factor inputs (see for instance Letterie, Pfann and Polder, 2004). Whether the lumpiness in one factor is caused by non-convexities in the adjustments of the input-factor itself, or lumpiness in the other input factors, is still an unsettled issue.[10]

The development in the log capital-labour intensity is depicted in figures 3, 4 and 5 (upper panels). For Electrical equipment, the growth rate of the capital-labour intensity from t-1 to $[t+2>$ is .17. The corresponding growth rates in Machinery and Retail trade are .34 and .32, respectively. Thus, investment spikes are accompanied by a much higher (long run) increase in capital-intensity in Machinery and Retail trade, than in Electrical equipment.

Note that the labour force composition, measured as the share of man-hours worked by high-skilled employees, is rather constant.[11] The reason for this may be that the investments during investment spikes are not really huge investments due to technological shocks. Such technological changes, and especially computerisation, is found to affect the organisation of work and to change the composition of the work force.[12] As there is no evidence in our study that investment spikes are associated with changes in the composition of the workforce at the micro level, it may indicate that technological changes are introduced in the firms as investments stretching out in time rather than as spikes. The lack of changes in the composition of the work force is also reflected by the fact that the average wages are rather unaffected by investment spikes in all the three industries.

In figures 3, 4 and 5 (lower panels) we present our results for labour productivity, labour force composition and wages. We find indications that labour productivity is changing during episodes where an investment spike takes place. Power (1998) finds that the productivity growth decreases with respect to the number of years elapsed since last investment spike.[13] But as she points out on page 307, "the quantitative magnitudes are small, and most of the growth rate coefficients are not statistically significant". Huggett and Ospina (2001) even find that there is a fall in the productivity growth associated with large equipment investments.

Summarised, our findings of small and insignificant changes in productivity associated with episodes of investment spikes are consistent with several international studies using econometric models on firm or plant level samples. The findings of unchanged labour force composition and wage are also consistent with such studies, indicating that productivity improvements are related to learning-by-doing more than instantaneous technological changes through investment spikes. A study with such a pattern is Bessen (2000), who finds that productivity at a newly created plant improves as the result of learning-by-doing, which is a much smoother process than what is typically followed by an

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[10] Abel and Eberly (1998) observe that lumpy employment pattern may be due to non-convexities in the adjustment of capital.

[11] This is also similar to the findings of Sakellaris (2004).

[12] See for instance Autor, Levy and Murnane (2003), and Berman, Bound and Machin (1998). See also Machin (2003) for a review of the literature on changes in skill composition as a response to technological change.

[13] See Sakellaris (2004) for related findings using US manufacturing data.

investment spike. As already noted, firms with investment spikes are in general substantial larger than firms without spikes. Thus selection may be an important determinant of the observed productivity pattern.

5. Conclusions

In this paper we have used a very rich and new, matched employer-employee data set from Norway for two manufacturing and one service industry to describe changes in the demand of capital and labour, the changes in labour productivity, and skill composition before, during, and after episodes of investment spikes. In summary we find that investments are lumpy, indicating that firms concentrate their investments into short periods of time. This is consistent with the existence of non-convexities in the adjustment costs for capital. We also find capital adjustments to be smoother in the service industry relative to the two manufacturing industries. This may indicate that the structure of the adjustment costs for capital is different in the rather capital-intensive manufacturing industry, relative to the more labour intensive retail industry.

The adjustments of the two input factors, capital and labour, are quite similar in Retail trade, while labour is a more flexible input factor than capital in the manufacturing industries. This latter finding may indicate that a firm may face non-convexities in the adjustment costs of several input factors. Thus modelling and analysing in a more structural way the demand for and the interrelatedness of several quasi-fixed factors will be important in future empirical research. Finally, we find that the changes in productivity associated with episodes of investment spikes are small. This last finding is consistent with the presence of adjustment costs of capital and labour, leading to disruption of existent production and therefore a very small, or even negative, effect of investment spikes. Thus, the findings indicate that productivity improvements may be related to learning-by-doing more than instantaneous technological changes through investment spikes.

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Appendix A

Detailed data description

As mentioned above the empirical analysis is carried out at the firm level. In the accounts statistics, a firm is defined as "the smallest legal unit comprising all economic activities engaged in by one and the same owner" and corresponds in general to the concept of a company (Statistics Norway, 2001). A firm can consist of one or more establishments. The establishment is the geographically local unit doing economic activity within an industry class. Another unit is the consolidated group, which consists of a parent company and one or more subsidiaries. Both the parent company and the subsidiaries are firms as defined here.

All joint-stock companies in Norway are obliged to publish a company account every year. The accounts statistics contain information obtained from the income statements and balance sheets of joint-stock companies, in particular, the information about the book values of a firm's tangible fixed assets at the end of a year, their depreciation and write-downs. However, it does not contain data on acquisitions of tangible fixed assets, since data on investments do not have a specific standard in the annual report, but are given in the notes to the latter and hence are not included in the statistics. The accounts statistics in its present version are available from 1993 to 2003.

The structural statistics are organized according to the NACE standard[14] and based on General Trading Statements, which are given in an appendix to the tax return. The EU's structural regulation requires statistics at the firm level. However, out of consideration to Norwegian users, local kind-of-activity units statistics have been compiled for employment, turnover, compensation of employees and gross investments. Since the manufacturing statistics are available at the firm level only from 1996, the data at the plant level were used for the aggregation to the firm level for the other years. In addition to some variables, which are common to those in the accounts statistics, the structural statistics contain data about acquisitions of tangible fixed assets and operational leasing. These data were matched with the data from the accounts statistics. As the firm identification number here and further we use the number given to the firm under registration in the Register of Enterprises, one of the Brønnøysund registers[15], which is operative from 1995.

The Register of Employers and Employees (REE) contains information obtained from the employers. All employers are obliged to send information to the REE about each individual employee: contract start and end, working hours, overtime and occupation. An exception is made only if a person works less than 4 hours per week in a given establishment and/or is employed for less than 6 days. In

[14] The Standard Industrial Classification (SN2002) in Statistics Norway is based on the EU standard NACE Rev. 1.1.

[15] www.brreg.no

this case the information is not sent to the REE. Besides this register contains identification numbers of the given firm, establishment and employee. These data are available for the years 1995-2004.

The Pay Statements Register (PSR) contains annual data obtained from Norwegian Internal Revenue Service. This register provides information on wages, bonuses and commissions, variable additional allowances and deductions, received by wage earner in each establishment. Moreover this data set includes some demographic information, as for instance age. Merging of this data with the REE using the personal identification number gives information about occupation and earnings of each wage earner in different establishments in the years 1995-2004, which can easily be aggregated to the firm level.

The National Education Database (NED) gathers all individually based statistics on education from primary to tertiary education and is provided by Statistics Norway since 1970. We use this dataset for identification of the length of education. For this purpose we utilize the first digit of the NUS-variable. This variable is constructed on the basis of Norwegian standards for education classification and is a six-digit number, the leading digit of which is the code of educational level of the person. According to the Norwegian standards for education classification (NUS89[16]), there are nine educational levels with the addition of the major group for "unspecified length of education". The educational levels are given in the Table A1.

Table A1. Educational levels in the NUS89

Tripartition of levels	Level	Class level
	0	Under school age
Primary education	1	1th-6th
Secondary education	2	7^{h}-9th
	3	10th
	4	11th -12th
Post-secondary education	5	13th-14th
	6	15th-16th
	7	17th-18th
	8	19th+
	9	Unspecified

[16] A new version of the Norwegian standards for education classification is available from 2000 (NUS2000). We have used the definitions of educational levels from the old version (Statistics Norway, 1989, p. 20), since individuals under our research have completed their education under the old educational system.

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