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**Working Paper**

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Working Paper, No. 2001:15

**Provided in Cooperation with:**

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Suggested Citation: Carlsson, Mikael; Laséen, Stefan (2001) : Capital Adjustment Patterns in Swedish Manufacturing Firms: What Model do they Suggest?, Working Paper, No. 2001:15, Uppsala University, Department of Economics, Uppsala

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# Capital Adjustment Patterns in Swedish Manufacturing Firms: What Model do they Suggest?\*

Mikael Carlsson and Stefan Laséen<sup>†</sup>

August 16, 2001

## Abstract

In this paper we study the capital adjustment process in Swedish manufacturing firms and relate the empirical findings to standard models of firm behavior in the presence of impediments to capital adjustments. We find that (i) a model with irreversible capital goes a very long way in capturing the salient features of firm-level capital adjustment behavior. To see this an integrated approach is necessary since different alternative models do well in certain comparative dimensions but not in others. (ii) The partial adjustment model generally fails to explain capital adjustment patterns. (iii) The capital accumulation process is a highly volatile and non-persistent process on the firm-level. (iv) Firms adjustment behavior is asymmetric in that they are more likely to tolerate excess capital than shortages of capital, and finally, (v) the estimated adjustment function implies that aggregate investment is relatively unresponsive to aggregate shocks in deep recessions as compared to the responsiveness in normal times.

JEL-Classification: E22; D24; L60

Keywords: Investment; Irreversibilities; Lumpiness; Manufacturing

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\*We are grateful to Fredrik Andersson, Per Engström, Per Johansson, Henrik Jordahl, Nils Gottfries, Oskar Nordström Skans and Olof Åslund and seminar participants at Uppsala University for helpful comments and suggestions. We are indebted to Jan Södersten for providing us with data and to Mark Doms and Timothy Dunne for sharing their Gauss code.

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# 1 Introduction

In this paper we study the capital adjustment process on firm-level data for the Swedish manufacturing industry and relate the empirical findings to standard models of firm behavior in the presence of adjustment impediments.

While most of the investment literature up to the 1990s focused on aggregate data the empirical evidence on firm level behavior is limited. Aggregate capital adjustment is generally found to be a smooth process, a behavior that is often captured by assuming that the representative firm faces convex adjustment costs. However, aggregation tends to smooth series and it is likely that using aggregate data creates an illusion of such adjustment behavior. Thus, it is not obvious that we can infer firm-level behavior from studying aggregate data. In fact, recent work by, for example, Nielsen & Schiantarelli (1996) and Doms & Dunne (1998) supports the view that the capital adjustment process is far from a smooth process on the micro-level. Doms & Dunne (1998) examine a 17-year sample of large continuing U.S. manufacturing plants and find that the largest investment episode on average accounts for 25 percent of the cumulative investments of an establishment during the 17-year period. Moreover, half of the establishments experienced capital growth rates in the proximity of 50 percent in a single year. Nielsen & Schiantarelli (1996) study Norwegian micro-data and find that investment rates in excess of 20 percent occur only 10 percent of the time, but account for almost a third of total real investment expenditure. Thus, long periods of relatively small changes are interrupted by investment spikes. This has been widely interpreted as evidence of S,s-type behavior on the firm-level, i.e. that firms invest only when their actual capital stock deviates sufficiently far from a target value, otherwise preferring to remain inactive to avoid lump-sum adjustment costs.

A useful observation when thinking of firm-level adjustment behavior is that capital is rarely at its "desired" level when adjustment costs and/or irreversibilities are of any importance. The size of capital adjustment depends on the type of adjustment cost the firm faces and on the size of the deviation between the desired and the actual stock of capital. Since a firm's desired stock of capital is not easily measured we approach the problem of

characterizing the capital adjustment process from two directions. First, we make as few assumptions as possible regarding the measurability of the desired stock of capital limiting ourselves to an assumption about the process governing the desired stock of capital. In the second part, on the other hand, we impose enough identifying assumptions to actually measure the desired stock of capital. This leads us to divide the paper into two parts.

Our main purpose in the first part of this paper is to, without imposing a specific theoretical structure, portray the equipment and machinery capital adjustment patterns both within and between firms in continuously operating Swedish manufacturing firms over the period 1979-1994.<sup>12</sup> In order to relate this description to existing investment models, we generate hypothetical investment patterns for three alternative investment models and compare these with the patterns in the data. We find that the capital adjustment process is indeed characterized by periods of high activity followed (and preceded) by periods of much lower activity. However, when studying these patterns more closely it is no longer obvious that the results support the view that they have been generated by an S,s model. Instead, we find that a model where firms face irreversibility constraints goes a long way in capturing the salient features of firm-level capital adjustment behavior. To see this an integrated approach is necessary. This is the case since the different alternative models do well in certain comparative dimensions but not so well in others.

In the second part of the paper we apply a more direct approach and estimate an adjustment function relating capital adjustment to the difference between the actual and desired capital stock. This difference is derived from the first order conditions of a standard neo-classical model. In this part of the paper we also examine the implications of our estimated adjustment function for aggregate capital adjustments.

Other findings, besides the one discussed above, of this paper are that (i) partial adjustment behavior, due to convex adjustment costs, generally fails to explain capital adjustment

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<sup>1</sup>We focus on equipment and machinery capital throughout the paper. This is due to that equipment capital is much less exposed to indivisibility constraints than structures - forcing firms to lumpy investment behavior. We will henceforth use the term capital synonymously with equipment capital.

<sup>2</sup>See Hansen & Lindberg (1997) for an Euler investment equation approach which uses the same data set.

patterns. (ii) The capital accumulation process is a highly volatile and non-persistent process on the firm-level. (iii) Firms adjustment behavior is asymmetric in that they are more likely to tolerate excess capital than shortages of capital. (iv) The estimated adjustment function implies that the aggregate growth rate of capital is relatively unresponsive to aggregate shocks, e.g. a monetary policy shock, in deep recessions as compared to the responsiveness in normal times.

This paper is organized as follows. Section 2 describes a stylized model of capital accumulation that nests several types of firm level behavior. Section 3 describes the data. Section 4 presents capital adjustment patterns and relate them to the predictions of three different investment models. Section 5 characterizes the micro-level adjustment behavior directly by estimating firm-level adjustment behavior. In section 6 we discuss implications for aggregation and section 7 concludes.

## 2 Model

Our starting point for modeling firm-level capital adjustment behavior is the observation that capital is rarely at its "desired" level when adjustment costs and/or irreversibilities are of any importance. To formalize this observation we let the deviation between desired and actual capital before adjustment, i.e. mandated capital adjustment, be denoted:

$$m_{i,t} = k_{i,t}^* - k_{i,t-1}. \quad (1)$$

where  $k_{i,t}^*$  and  $k_{i,t-1}$  represent the natural log of desired and actual capital in firm  $i$  at time  $t$ . Positive values of  $m$  thus indicate capital shortage, whereas negative values reflect excess capital.

For a complete model of firm-level capital adjustment we need two additional building blocks. First, we need to determine the desired stock of capital. Second, we need an expression mapping adjustment incentives ( $m_{i,t}$ ) to actual adjustment ( $k_{i,t} - k_{i,t-1}$ ) - that is, the firms adjustment behavior.

## The Desired Stock of Capital

This section draws on Caballero, Engel & Haltiwanger (1995) and derives a measure of the desired capital stock. Let gross output be produced by the following production function:

$$Y = AK^\gamma F^\phi, \quad \gamma + \phi < 1, \quad (2)$$

where  $A$  is an index measuring technology,  $K$  is the stock of capital and  $F$  is all other variable factors of production. It is assumed that only adjustment of the stock of capital is associated with adjustment costs - thus, all other variable factors,  $F$ , are flexible. Moreover, the production function is assumed to exhibit decreasing returns to scale due to fixed factors (other than equipment). Profit is given by

$$\Pi = Y - P_F F - CK \quad (3)$$

where  $P_F$  is the real price of flexible factors and  $C$  is the real user cost of capital. Optimizing over flexible factors yields the following first order condition:

$$F = \frac{\mu}{AK^\gamma \phi} \frac{1}{\phi-1}. \quad (4)$$

Using (4), we can rewrite (2) as:

$$Y = \Psi K^{\frac{\gamma}{1-\phi}}, \quad (5)$$

where  $\Psi = A^{1/(1-\phi)} (P_F/\phi)^{\phi/(\phi-1)}$ . The ratio of actual output to actual capital can, using (5), be written as:

$$\frac{Y}{K} = \Psi K^{\frac{\gamma+\phi-1}{1-\phi}}. \quad (6)$$

Using (6) we arrive at a useful expression for the actual stock of capital:

$$K = \frac{\mu}{K\Psi} \frac{1}{-\eta}, \quad (7)$$

where  $-\eta = (1 - \phi)/(1 - \gamma - \phi)$ . We define frictionless capital as the stock of capital the firm would choose if it did not face adjustment costs. The first order condition determining the frictionless stock of capital is given by:

$$\mathcal{K} = \frac{\mu}{\gamma} \frac{1-\phi}{\Psi} \frac{1}{-\eta}, \quad (8)$$

where we have solved the first order condition for capital and then used (5) to eliminate flexible factors. Desired capital, on the other hand, corresponds to the stock of capital the firm would choose if the adjustment cost were temporarily removed. Following Caballero et al. (1995) we assume that the desired stock of capital,  $K^*$ , is proportional to the frictionless stock of capital, i.e.:<sup>3</sup>

$$K^* = d\bar{K}. \quad (9)$$

Note that the desired stock of capital is determined by the technology index, factor prices of flexible factors and user cost of capital which all can be reasonably well approximated as random walks with drift. For example, Dufwenberg, Koskenkylä & Södersten (1994) can not reject the null that the user cost of capital is a random walk in Swedish data. Hence, it follows that the process for the desired stock of capital may also be modeled as a random walk with drift:

$$k_{i,t}^* = k_{i,t-1}^* + \xi_{i,t}, \quad \xi_{i,t} \sim N^{\text{f}}[\mu, \sigma^2], \quad (10)$$

where the forcing process,  $\xi_{i,t}$ , is assumed to be *i.i.d* across firms and time.

### Adjustment Behavior

We consider three standard models of firm level adjustment behavior. The first case is partial adjustment toward the desired stock of capital. In this case we will have that the firm reduces the deviation between the desired and the actual stock of capital with a fraction,  $\lambda$ , each period,

$$k_{i,t} - k_{i,t-1} = \lambda m_{i,t}. \quad (11)$$

This type of gradual adjustment was often postulated in the early investment literature to account for the serial correlation of aggregate investment data. Later, micro foundations

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<sup>3</sup>According to Bertola & Caballero (1994) this assumption is consistent with the behavior of a firm with a isoelastic profit function that faces shocks that have independent increments. See also Caballero et al. (1995) for a discussion of this assumption.

was provided for this kind of adjustment model by assuming that the firm faces symmetric convex adjustment costs (see e.g. Hamermesh & Pfann 1996 for a survey).

The second case we consider is lumpy capital adjustment behavior due to non-convex adjustment costs. The optimal capital adjustment behavior for a firm facing non-convex adjustment costs is captured by a  $S, s$  rule,

$$k_{i,t} - k_{i,t-1} = \begin{cases} \frac{1}{2} m_{i,t} & \text{if } m_{i,t} \geq U \text{ or } m_{i,t} \leq L \\ 0 & \text{if } U > m_{i,t} > L \end{cases} . \quad (12)$$

That is, if the deviation between the desired capital stock in period  $t$  and the actual capital stock before adjustment, i.e.  $m$ , is larger (smaller) than or equal to a trigger level  $U$  ( $L$ ), the firm will increase (decrease) its capital stock such that  $m = 0$  after adjustment. On the other hand, if the value of  $m$  is within the upper,  $U$ , and the lower,  $L$ , trigger levels before adjustment, the firms optimal behavior is to keep the level of the capital stock constant.

The third case we consider is capital adjustment behavior when capital is completely irreversible. This would be the case if e.g. capital is firm specific and has no value on the second hand market. Under this restriction Bertola & Caballero (1994) show that the optimal behavior is to adjust fully to the desired level of capital if mandated capital adjustment is positive and let capital depreciate towards the desired level of capital if mandated capital adjustment is negative,

$$k_{i,t} - k_{i,t-1} = \begin{cases} \frac{1}{2} m_{i,t} & \text{if } m_{i,t} > -\delta_i \\ -\delta_i & \text{if } m_{i,t} \leq -\delta_i \end{cases} , \quad (13)$$

where  $\delta_i$  is the depreciation rate.

In section 4 below we will compare predictions from the three investment models to the patterns present in the data in several different dimensions. To this end, we simulate a panel of firms calibrated to correspond to the firms generating the real data set. We use (10) to generate the desired stock of capital. If we then apply the different adjustment rules (11), (12) or (13) we have a complete characterization of the capital adjustment process for our simulated panel of firms.



### 3 Data

The data we use consists of a balanced panel of ongoing manufacturing firms drawn from the CoSta database (described in Hansen 1999).<sup>4</sup> This database is, in turn, based on Enterprises - Financial Accounts collected by Statistics Sweden, containing annual data for non-financial firms located in Sweden. Given the availability of data and after standard cleaning procedures, described in appendix A, we are left with 341 firms observed over the period 1979 - 1994.

The capital stocks are estimated using the perpetual inventory method:

$$K_{i,t} = (1 - \delta_i) K_{i,t-1} + I_{i,t}, \quad (14)$$

where  $I$  is investments. Throughout the paper investments is defined as real capital expenditures less the real market value of sold capital (see appendix A for a detailed description of the variables used in the paper). As is evident from (14), this method requires an assumption about the initial value of the stock of capital. We take the starting value from accounting data and to dampen the effect of this assumption we only use the years 1984-1994 in the analysis. We will return to how plausible this initial assumption is in the next section where we study the cyclicity of the growth rates of capital.

There obviously exist numerous ways to study firm level capital accumulation patterns. The measure of the growth rate of capital that will be studied in the next section is defined for firm  $i$  at time  $t$  as:

$$GK_{i,t} = \frac{K_{i,t} - K_{i,t-1}}{K_{i,t-1}}. \quad (15)$$

This measure is a monotonic transformation of the measure used by Davis, Haltiwanger & Schuh (1997) and differs only by  $\delta$  from the measure used by Nielsen & Schiantarelli (1996). That is, our measure implies that a zero growth rate of capital corresponds to an unchanged stock of capital.

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<sup>4</sup>To check if our results are sensitive to the selection procedure we present results from an unbalanced panel in Appendix D.

## 4 Firm level capital accumulation patterns

In this section we focus on capital adjustment patterns and relate them to the predictions from the stylized models of firm level adjustment behavior presented in section 2.

### Ranking of Growth Rates

An informative way to assess firms' adjustment behavior, without imposing any theory, is to rank the growth rates of capital for each firm from highest to lowest (see e.g. Doms & Dunne 1998). Define  $GK_i = \{GK_{i,t}\}_{t=1984}^{1994}$ ,  $GK_i^1 = \max(GK_i)$  and  $GK_i^j = \max_{k=1}^{j-1} GK_i^k$  for  $j = 2, \dots, 11$ . The mean growth rate for the  $j^{th}$  largest growth rate is now given by

$$R^j = \frac{1}{n} \sum_i GK_i^j, \quad j = 1, \dots, 11. \quad (16)$$

Figure (1) presents these ranked growth rates.

The mean growth rate of capital for observations with rank 1 ( $R^1$ ) is 0.57 which is twice as high as the second highest growth rate ( $R^2 = 0.26$ ) and three times as high as the third highest growth rate ( $R^3 = 0.17$ ). Thus, firms experience relatively few periods of large capital adjustment. This pattern is similar to what is found by e.g. Doms & Dunne (1998) and Nielsen & Schiantarelli (1996) and has been widely interpreted as evidence in favor of S,s behavior on the micro-level. However, as will be shown below, this interpretation is no longer obvious when we also consider irreversibility.

### Simulated Growth Rates

To see what is implied by the different models of capital adjustment behavior we investigate whether they can replicate the pattern that we observe in figure 1. We calibrate the models by minimizing the mean squared error (MSE) between the ranked capital adjustment rates,  $R^j$ , implied by the data and the simulated values,  $R^j(\Theta)$  where  $\Theta$  is the vector of parameters. Hence,  $\Theta$  equals  $\lambda$  for the partial adjustment model,  $(U, L)$  for the S,s adjustment model, and  $\emptyset$  in the irreversible adjustment model. The MSE is then given by

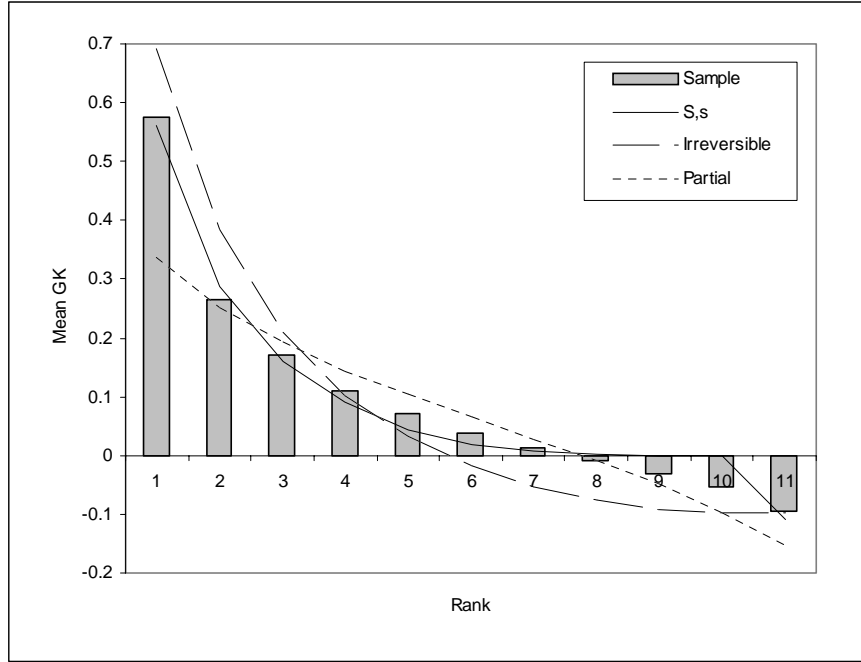


Figure 1: Mean growth rate of capital by rank ( $R^j$ ) for the sample and for the three simulated adjustment behaviors.

$$MSE(\Theta) = \frac{1}{1 - \text{rank}(\Theta)} \sum_{j=1}^{\text{rank}(\Theta)} (R^j - R^j(\Theta))^2,$$

where  $R^j(\Theta)$  has been generated from the three models above with the assumption that the desired stock of capital follows a random walk with drift – given by equation (10).<sup>5</sup>

The simulations are performed with  $n = 341$  firms for  $T = 300$  periods.<sup>6</sup> The simulated

<sup>5</sup>Since the model is expressed in log differences we also express the data in log differences when minimizing the  $MSE$ . Then we use the monotonic transformation,  $GK_{i,t} = \exp(\ln(k_{i,t}/k_{i,t-1})) - 1$ , to compare the results of the simulation with the data in terms of percentage change. To minimize the  $MSE$  in the simulation with the S,s setup we have utilized a grid search. The grid size was first set to 0.1. We then search on a finer grid ( $\Delta 0.01$ ) around the optimal values ( $\pm 0.05$ ) retrieved from the first coarser grid search. To minimize the  $MSE$  in the simulation with the convex adjustment costs we used the Quasi-Newton minimization routine in Gauss 3.5. The model is similar to Doms & Dunne (1998). However, Doms & Dunne (1998) only analyze the S,s. adjustment rule.

<sup>6</sup>The number of firms is chosen to match our panel, the depreciation rates are set to have the same values

growth rates of capital,  $GK_{i,t}(\Theta)$ , are calculated for the last 11 periods ( $t = 290, 291, \dots, 300$ ) and ranked as was done with the real data in equation (16). A problem when calibrating the model is to pin down the mean and standard deviation of the forcing process in equation (10). To do this we construct a measure of the firm's desired capital stock (described in in section 5). Using this measure, our data suggests that the mean and the standard deviation of the forcing process equals 0.049 and 0.378. This value of  $\sigma$  is higher than the one used by Doms & Dunne (1998) for the U.S. economy ( $\sigma = 0.18$ ). An explanation for this finding might be that Swedish firms are more exposed international conditions than what is the case for firms in the United States.

The first simulation introduces partial adjustment behavior. The  $\lambda$ , i.e. the fraction of  $m$  that is closed in each period, that minimizes the MSE equals 0.35. The corresponding MSE is 0.0073. It is evident from figure 1 that partial adjustment does not succeed to capture the salient features of the data. Most importantly, the partial adjustment model can not reproduce the sharp drop in growth rates that we see in the data after the first rank. The mean growth rate is 0.34 for rank 1 and 0.25 for rank 2. The partial adjustment model implies symmetric capital adjustments which does not seem to be a fair approximation of actual adjustment behavior.

The second simulation is with the S,s adjustment model. It is obvious that S,s model provides an improvement relative to the partial adjustment model. The main feature about this simulation is how the simulated values are able to track the sharp fall in the growth rates of capital in the data after the first rank. Obviously, this is also what we should expect since the S,s model has the most parameters. The observed growth rates of capital are slightly higher for intermediate ranks and lower for the ranks 8 to 10 than what we are able to reproduce with the S,s model of the model. The trigger levels, expressed in the log difference space, that minimize the *MSE* at 0.000713 are  $U = 0.02$  and  $L = -2.07$ . Thus, the firm will adjust its capital stock up to the desired stock of capital if the desired stock of capital is 1.02 times larger than the actual stock of capital. Analogously, the lower trigger

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and distribution as the firms in the panel and the number of periods is chosen to assure that the initial conditions are irrelevant.

level implies that the firm will adjust its capital stock down to the desired stock of capital if the actual stock of capital is 7.92 times larger than the desired stock of capital. It should be noted, however, that the optimal S,s behavior implies that we should only observe negative adjustment that are larger than  $-87$  percent, whereas the largest negative adjustment in the sample is  $-53$  percent. It is interesting to see that the trigger levels that minimize the *MSE* comes very close to what one would set them to in order to mimic an irreversibility constraint as close as possible with the S,s model. That is set  $U$  to zero and  $L$  to a very low value.<sup>7</sup>

Given the results of the S,s model it is not surprising that the irreversibility model turns out to yield a similar adjustment pattern. Although for all ranks, besides rank 4 and 11, the S,s model does a better job. The mean growth rate levels off on approximately  $-10$  percent which is what we should expect since the mean rate of depreciation equals almost 10 percent. Remember that when capital is completely irreversible, the stock of capital can only be lowered by allowing it to depreciate, which implies that the growth rate for rank 11 should be close to the mean rate of depreciation. Although there are observations of  $GK$  in the sample that are lower than the depreciation rate, something we should not observe if capital is completely irreversible, these observations constitutes only four percent of the total number of observations in the sample.

Finally, when comparing the *MSE*:s we see that the *MSE* for the irreversible setup (0.00543) is about 74 percent of the *MSE* for the partial adjustment model (0.0073). However, the *MSE* of the S,s model (0.000713) is only about 13 percent of the *MSE* of the irreversibility setup. The conclusion from this section is that the S,s model fits the patterns in the data best, followed by the irreversibility model. However, it is interesting to see that the S,s model accomplish this by setting the trigger levels as if to mimic an irreversibility constraint.

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<sup>7</sup>Note that the irreversible model is not a special case of the S,s model because in the S,s model we have assumed that if the firm allows the capital stock to depreciate it must pay a fixed adjustment cost.

## Within-Firm Timing Pattern of Capital Adjustment

Another interesting and informative aspect of the capital adjustment process is the within-firm timing patterns of capital adjustment. More specifically, we are interested in what happens with the growth rates the years before and after the year with the highest growth rate. To calculate these growth rates define  $GK_{i,t-1}^1$  to be the growth rate for firm  $i$  the year before the year with the highest growth rate. We can now define

$$R_{t+l}^1 = \frac{1}{n} \times_i GK_{i,t+l}^1, \quad l = -2, -1, \dots, 2.$$

The mean growth rate across firms one year before the year with the highest growth rate is consequently denoted  $R_{t-1}^1$ . Figure 2 depicts  $R_{t-2}^1, R_{t-1}^1, R_t^1, R_{t+1}^1$  and  $R_{t+2}^1$ . It is evident that large capital adjustments do not seem to be neither preceded, nor followed, by large capital adjustments, as would be expected if firms followed some smooth adjustment rule. Instead, the timing pattern indicates that capital adjustments are, to a large extent, performed in bursts.<sup>8</sup> Thus, we see no signs of the smooth behavior found on the aggregate level when studying firm-level data.

What implication do the different adjustment models have for the within-firm timing patterns of capital adjustment? To shed light on this issue we calculated the mean growth rates of capital that surrounds the maximum capital growth rate for the simulated data. Figure 2 depicts these mean growth rates for the partial adjustment, the S,s and the irreversible model together with the growth rate for the real data. Again, the simulated timing patterns for the partial adjustment model are unable to reproduce the pattern that we see in our data. Instead, this model implies a gradual build-up of a large deviation in  $m$  before the rank 1 observation followed by a gradual reduction of this deviation. The timing pattern in the data is much more in line with the S,s or irreversible investment models in which firms are at a much lower level of investment spending before and after an investment spike.

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<sup>8</sup>In appendix C we show that the rank and the timing patterns are similar across firms of different size. Thus, the results can not be argued to be driven by a large number of small firms restricted by indivisibility constraints in their adjustment behavior.

This is natural since both these models imply that there should be no persistence in positive capital adjustments.

The conclusion from this section is that the timing pattern in the data seems to be almost equally well described by the S,s and the irreversibility model. The partial adjustment model is unable to reproduce the timing pattern in the data.

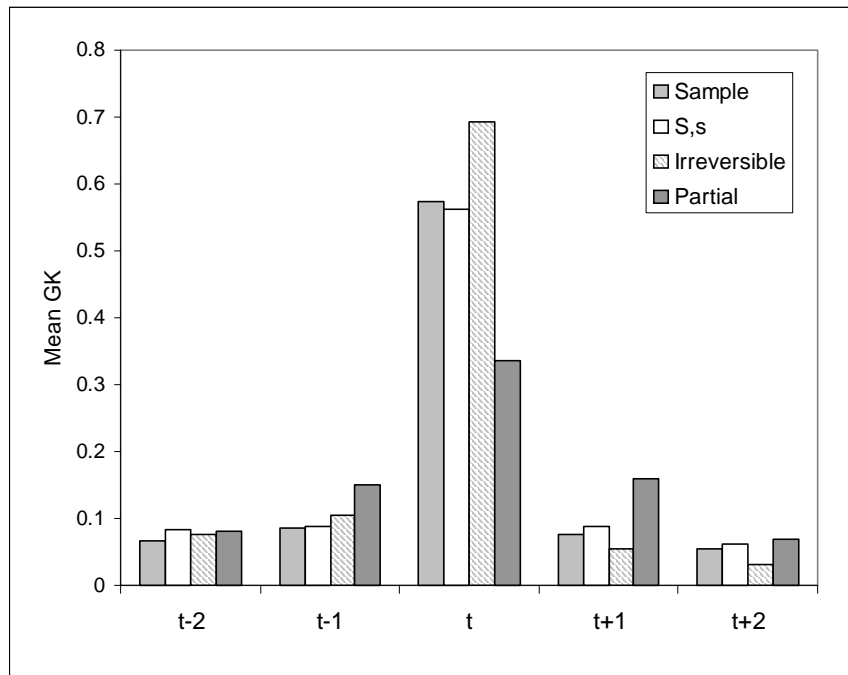


Figure 2: Mean growth rate of capital for the years surrounding rank 1 ( $R_{t+l}^1$  where  $l = -2, -1, \dots, 2$ ) for the sample and for the simulated adjustment models.

### Distribution of Growth Rates

The density of the growth rates of capital is plotted in figure 3 (top left panel).<sup>9</sup> The distribution is skewed to the positive side and indicates a large portion of relatively large positive capital adjustments. The negative adjustments seem, however, to be few and relatively small. A large portion of the observations are bunched up around zero. However,

<sup>9</sup>Besides a zero line, we have also included a line at  $-0.1375$  which is the negative of the highest rate of depreciation in our sample.

it is hard to detect any other attractors in the distribution. A concern when focusing on ongoing firms is sample selection. When selecting ongoing firms we might only select firms with small negative adjustments - biasing the results towards finding irreversibility. However, the distribution of the corresponding unbalanced panel, presented in Appendix E, is very similar to the distribution of the balanced panel.<sup>10</sup> Thus suggesting that the sample selection problem is not a crucial issue here.

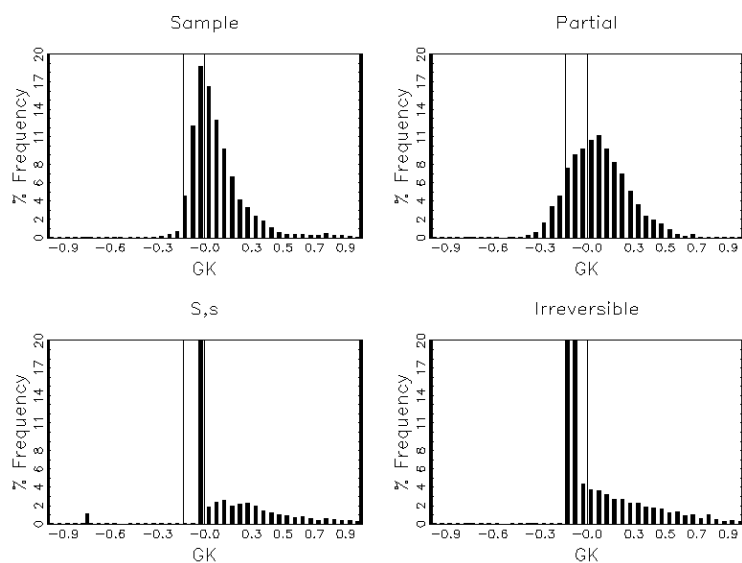


Figure 3: Density of the growth rates of capital for the sample and for the three cases of simulated adjustment behaviour.

The corresponding distributions of the simulations are presented in the other panels of figure 3. The partial adjustment model (upper right panel) gives rise to a distribution that is much more symmetric than the real data. The S,s model (lower left panel) predicts that there should be a large mass of observations at zero due to the assumption that there is fixed

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<sup>10</sup>The unbalanced panel corresponds to a sample of 2321 firms observed at least seven consecutive periods. This sample is drawn from the same data as the balanced panel and obtained using the same cleaning procedures as the balanced panel. After calculating the capital stocks by the perpetual inventory method (the reason why we need a series of consecutive observations) we drop the first four observations to dampen the effects of the initial condition.



cost in adjusting the level of capital. Note also the spike right below -0.9 which is due to negative capital adjustment. These large negative adjustments are, however, not a feature of the real data, whereas small negative adjustments do occur. In the lower right panel the results for the irreversible case is presented. As expected the observations bunch up against minus the depreciation rate since this is the only way to alleviate negative deviations between the desired and the actual capital stock. Overall, we find the results presented in figure 3 is suggestive of irreversibility as being a prominent feature of the data.

### Cyclical Movements in Growth Rates

Figure 4 shows a decomposition of the aggregate growth rate of capital in the sample by rank, where the sample aggregate growth rate year  $t$  is defined as:

$$GK_{A,t} = \sum_i \omega_{i,t} \frac{(K_{i,t} - K_{i,t-1})}{K_{i,t-1}}, \quad (17)$$

with the weights defined as  $\omega_{i,t} = K_{i,t-1} / \sum_i K_{i,t-1}$ . The figure conveys that fluctuations in the aggregate growth rate of capital are mainly accounted for by rank 1 and 2. In fact, the growth rate of rank 1 accounted for all of the total growth rate during the recession years 1992 to 1994. Thus, the contribution of the ranks 2 to 11 to the aggregate growth rate cancel out. Moreover, only about four percent of the firms (approximately 14 firms) were, per year, assigned rank 1 during this period, as can be seen in figure 5. Hence, large capital adjustments of relatively few firms seems to an important determinant of aggregate changes.

Figure 5 shows the share of firms in the sample with rank 1, 2, 10 and 11 for each year. The figure clearly reflects the negative effect of the recession on the share of firms with low ranks during the early 1990s as well as the favorable effect of the recovery in 1994.<sup>11</sup>

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<sup>11</sup>Another relevant aspect of figure (5) is that the share of firms with rank 1 increases from 1984 to 1985 and is relatively stable throughout the 1980s. This would not have been the case if the start value,  $K_{1,1979}$ , used in the perpetual inventory formula (14) had been too low. A priori one would suspect the starting value taken from accounting data to be too low. This is the case since measures of the stock of capital taken from accounting data is only stated in nominal terms. Thus, investment goods inflation implies that older vintages of capital will be underestimated when the current value of the stock is deflated with the current value of the investment deflator.

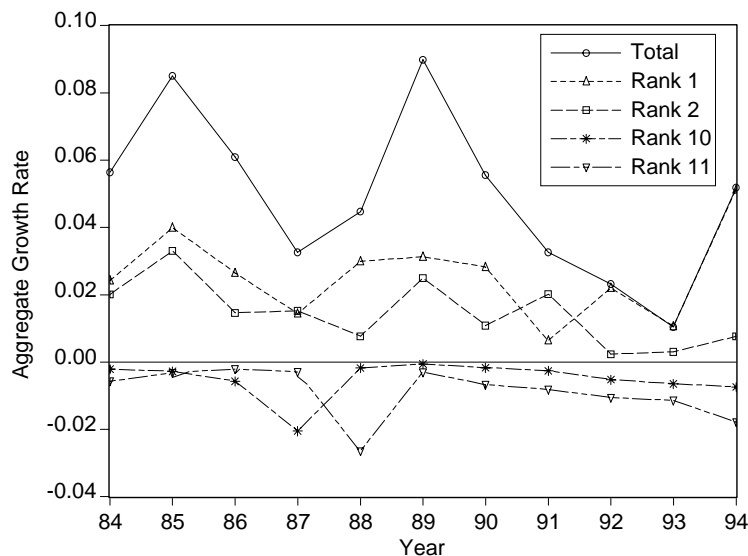


Figure 4: Aggregate growth rate of capital and the weighted growth rates of rank 1, 2, 10 and 11.

In appendix D we show that the rank and timing patterns in investments are similar to corresponding capital growth rate patterns. Thus, supporting that the results are not due to our assumption about how the stock of capital evolves over time.

## 5 Firm-level adjustment behavior

In this section we take a somewhat more direct approach to characterizing micro-level adjustment behavior. That is, here we estimate the function describing how the firm reacts to deviations between the desired and the actual stock of capital before adjustment, i.e.  $m_{i,t}$ . To derive a measure of  $m_{i,t}$  we can use the desired capital stock, equation (9), and the actual capital stock, equation (7), that were derived in section 5.2. The ratio of (9) and (7) yields the following expression

$$\frac{K^*}{K} = d \frac{\mu}{\gamma} \frac{1 - \phi C}{\Psi} \left( \frac{Y}{K\Psi} \right)^{\eta} \quad (18)$$

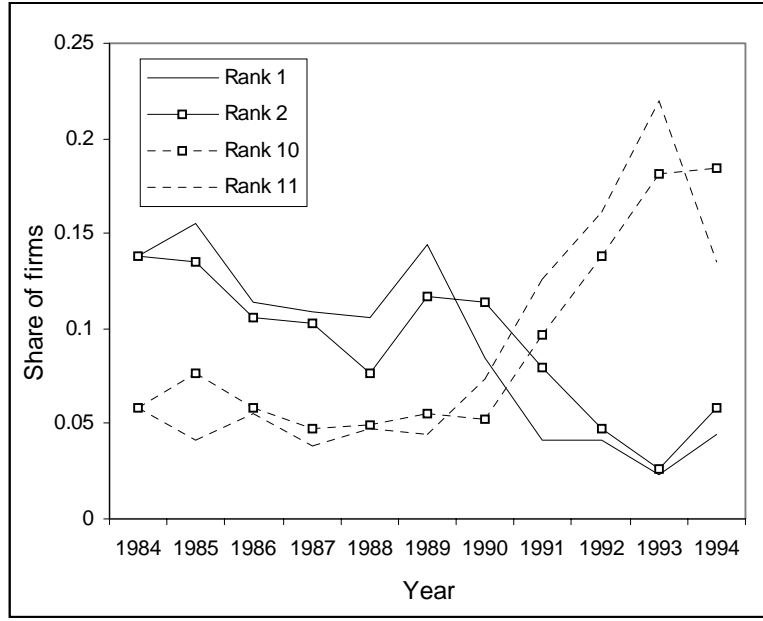


Figure 5: Share of firms in the sample with rank 1, 2, 10 and 11 for each year.

Taking the log of (18) on both sides and collecting terms yields:

$$k^* - k = \eta \left( y - k - c - \ln \gamma + \ln \frac{1 - \phi}{\gamma} \right) + \frac{d^s}{\eta}, \quad (19)$$

where lower case letters denotes the log of the variable. Up to this point no explicit timing has been assumed. However, since we seek an expression for the gap between the desired stock of capital and the actual stock of capital before adjustment (mandated capital adjustment) such an assumption is required. The following assumptions are made: first, the firm produces their output with the capital stock in period  $t-1$ . This assumption is reasonable since the capital stock is measured at the end of each period. Second, the timing within each period is as follows: first shocks are realized, second adjustments are made, third production takes place and finally capital adjustments become productive. Since production takes place with the stock of capital lagged one period, what matters for the firm when deciding upon the size of the capital adjustment is the expectation of the desired stock of capital in period  $t+1$  in  $t$ . Under the assumption that  $k^*$  follows a random walk with drift, mandated capital

adjustment can then be written as:

$$m_{i,t} = k_{i,t}^* - k_{i,t-1} = \eta [y_{i,t} - k_{i,t-1} - c_{i,t} + v_i], \quad (20)$$

where  $v_i$  denotes the sum of the constant terms. Finally, we follow Caballero et al. (1995) and approximate  $\eta$  by  $1/(1 - \alpha_i)$ , where  $\alpha_i$  is the cost share of equipment capital in total revenue. Intuitively, expression (20) implies that the deviation between the desired and the actual stock of capital is proportional to the imbalance in the standard Jorgensonian (Neoclassical) first order condition for capital.

To estimate the mandated capital adjustment from (20) we only need to obtain estimates of the firm specific constants,  $v_i$ . To this end we make use of the fact that the firm eventually will eliminate deviations between the desired and the actual stock of capital. Hence, mandated capital adjustment will be zero in the long run. This in turn implies that the error term,  $\varepsilon_{i,t}$ , in the following equation will be stationary,<sup>12</sup>

$$k_{i,t-1} - y_{i,t} + c_{i,t} = v_i + \varepsilon_{i,t}. \quad (21)$$

The constants,  $v_i$ , can thus be consistently estimated with OLS. Using this estimate of the constants we can back-out the mandated capital adjustment from (20). As a final step, the measure of mandated capital adjustment is expressed as deviation in percentages (denoted by superscript  $p$ ) instead of a log deviation.<sup>13</sup>

Given that the irreversible and the S,s models of capital adjustment behavior imply that the adjustment function relating actual adjustment to mandated capital adjustment, i.e.:

$$GK_{i,t} = f(m_{i,t}^p), \quad (22)$$

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<sup>12</sup>We have also estimated mandated capital adjustment by running the following cointegration regression:  $k_{i,t-1} - y_{i,t} = v_i + \theta c_{i,t} + \varepsilon_{i,t}$ . This procedure yields an manufacturing wide estimate of  $\theta = -0.63$  with a S.D. error of 0.02. Using this estimate of  $\theta$  together with the estimates of the constants from this regression do not change the results in this and the next section qualitatively. We also experimented with including lagged differences of the cost of capital, as suggested by Caballero (1994), to mitigate the small sample attenuation bias present in this type of cointegrating regressions. However, this did not bring our estimate of  $\theta$  any closer to its theoretical value of minus unity.

<sup>13</sup>To do this we use the following transformation  $m_{i,t}^p = (K_{i,t}^* - K_{i,t-1})/K_{i,t-1} = e^{m_{i,t}} - 1$ .

might not be well behaved and since we want to describe capital adjustment without imposing a specific theoretical structure we apply a non-parametric approach to estimation. More specifically, we take the averages of actual adjustment,  $GK_{i,t}$ , over nine intervals defined on  $m_{i,t}^p \in [-0.8, 1]$ .<sup>14</sup>

In figure 6 the resulting average adjustment function is depicted, where the mean of each interval has been joined together. There are several interesting aspects of the empirical adjustment function. First, the function is clearly upward sloping, supporting the notion that the approach does capture investment incentives. On average, the largest positive capital adjustments takes place when mandated capital adjustment are as highest. Second, the function is suggestive of an asymmetric response to capital surpluses and capital shortages. That is, firms seem to be less responsive to capital surpluses relative to capital shortages on average. In figure 6 we have also plotted the distribution of mandated capital adjustment which indicates that the mass of observation is well captured by the interval -0.8 to 1. Moreover, the distribution indicates that the asymmetry between positive and negative mandated adjustments take place where there is high density of observations.

Next, we compare the empirical adjustment function, obtained by the non-parametric approach, to what is implied by the simulation of different capital adjustment models.

The empirical adjustment function implies that the firms are relatively unresponsive to negative deviations, as predicted by irreversibility. The estimated S,s rule also implies that the firm should not react to negative deviations in the interval presented in figure 6. However, the S,s model, fitted above, suggest that the firms should react with a large negative adjustment when adjusting. Such large negative capital adjustments are not present in the data (see section 5.4), suggesting that the irreversibility model provides a better description of firm behavior when mandated capital adjustment is negative. On the positive side we see that the empirical adjustment function seems to be flatter than what is implied by any of the adjustment models studied in this paper. This might be due to measurement errors in

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<sup>14</sup>The function thus corresponds to a partition of  $m_{i,t}^p$  into 9 intervals between -0.8 to 1. The interval between -0.8 and 1 includes 96 percent of the observations on  $m_{i,t}^p$ .

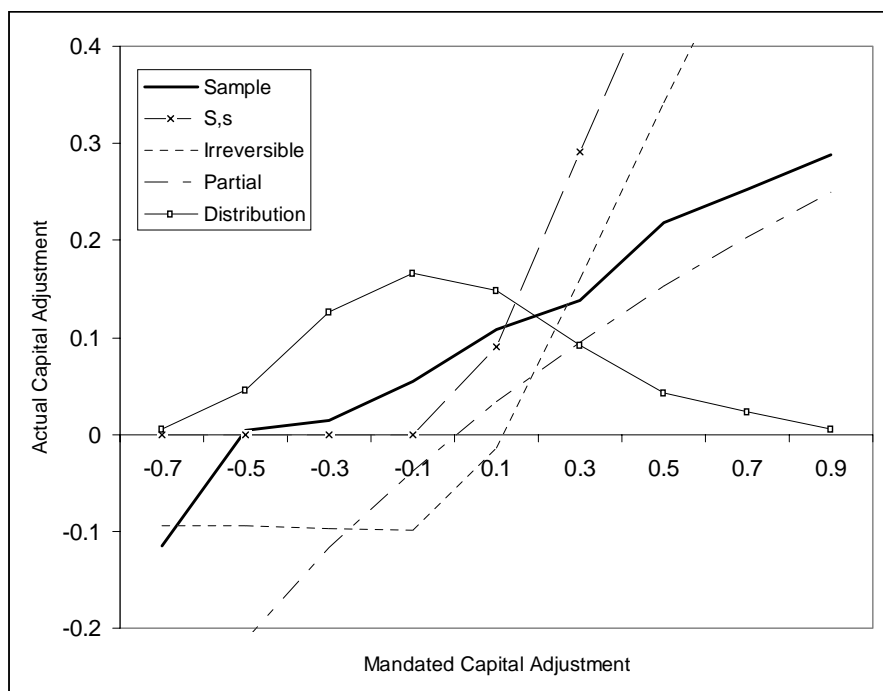


Figure 6: Empirical and simulated adjustment function, i.e. the averages of actual adjustment,  $GK_{i,t}$ , over nine intervals defined on  $m^p \in [-0.8, 1]$ .

our measure of mandated capital investments.<sup>15</sup> These errors would then attenuate the slope of the estimate adjustment function. In appendix E we experiment with lagged mandated capital adjustments as instrument to control for classical measurement errors. Although this produces a much steeper adjustment function it does not change the results qualitatively. Moreover, the instrument that is used is questionable if the true adjustment function is non-linear (see Appendix E for a discussion).

The first impression of the results in this section is that none of our candidates (partial, irreversible or S,s adjustment model) can fully explain the observed behavior. Nevertheless, the overall conclusion is that firms seem to be less responsive to capital surpluses relative to capital shortages, something which cannot be explained by a partial adjustment model.

<sup>15</sup>Another explanation for this might be financial constraints, something which we do not consider in this paper.

## 6 Implications for aggregate investments

Are the results from the previous sections important for understanding aggregate investment? To analyze this we start by approximating the empirical adjustment function by a polynomial:

$$GK_{A,t} = \sum_i \omega_{i,t} \left( a_0 + \sum_{j=1}^{\#} a_j m_{i,t}^p \right), \quad (23)$$

where we have used (22) and (17). In a world without frictions  $a_1 = 1$  and for the partial adjustment model  $a_1 \in (0, 1)$  with  $a_j = 0 \forall j > 1$  in both cases. Now consider the effect of an aggregate shock that shifts the distribution of mandated adjustment to the positive side while preserving the shape of the distribution on the aggregate growth rate of capital. An important implication of the two special cases mentioned above is that the response of aggregate capital accumulation to an aggregate shock is independent of the distribution of mandated capital adjustment across firms since:

$$\sum_i \frac{\partial GK_{A,t}}{\partial m_{i,t}^p} = a_1, \quad (24)$$

where the derivative measures the composite effect of an increment in each firms mandated capital adjustment on the aggregate growth rate of capital. However, if the adjustment function is non-linear, as is the case for the S,s or the irreversible model, the responsiveness to aggregate shocks will also depend on the cross section of mandated capital adjustment, i.e.:

$$\sum_i \frac{\partial GK_{A,t}}{\partial m_{i,t}^p} = \sum_i \omega_{i,t} \left( a_1 + \sum_{j=2}^{\#} a_j j m_{i,t}^{p-j} \right). \quad (25)$$

Hence, the response of aggregate accumulation to an aggregate shock will be determined by the shape of the distribution of  $m_{i,t}^p$  across firms (i.e. higher order moments than the first).

To empirically assess how important movements in the cross section of  $m_{i,t}^p$  is for determining the aggregate growth rate of capital we take the following approach: first, we estimate the parameters of the polynomial approximation and use these estimates to evaluate (25) at the distribution of  $m_{i,t}^p$  for each year in the sample.<sup>16</sup> Second, we compare the results from

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<sup>16</sup>The parameters of the polynomial approximation are estimated by fitting a high order polynomial to the nine points of the empirical adjustment function.

the first step to the derivative (24) obtained by restricting  $a_j = 0 \forall j > 1$  when estimating the polynomial approximation. Since we have relatively few observations for  $m^p > 1$  and hence limited information about the shape of the adjustment function beyond this level, we restrict our attention to firms that had a mandated capital adjustment within  $-0.8$  to  $1$  throughout the sample period 1984-1994, leaving us with a sample of 233 firms.<sup>17</sup>

In figure 7 the responsiveness for aggregate capital growth to aggregate shocks is depicted by year.

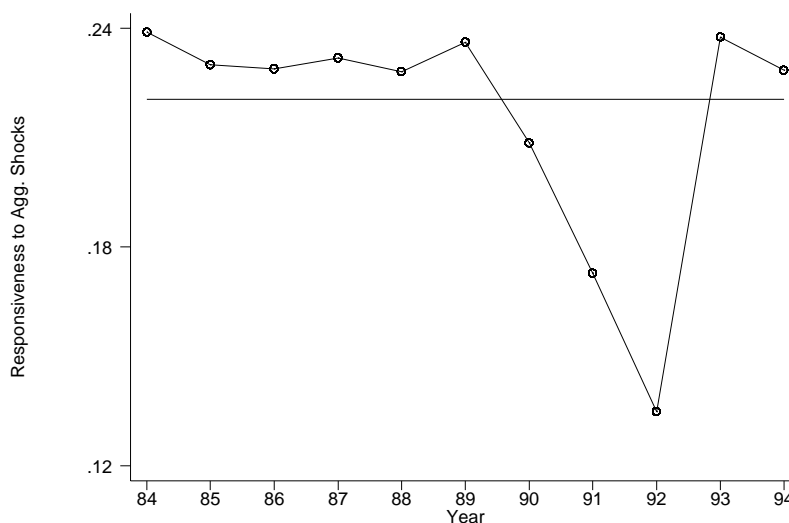


Figure 7: Responsiveness of aggregate capital growth to aggregate shocks.

Thus, given that the adjustment function were linear, a one percentage point increase in all firms mandated capital adjustment would increase the aggregate growth rate of capital with about 0.22 percentage points, illustrated by the straight line in figure (7). However, allowing for nonlinearity in the adjustment function has an important effect for the responsiveness of aggregate capital growth to aggregate shocks in times with low economic activity. In the midst of the recession in the beginning of the 1990s the responsiveness was only about half of its average in normal times (0.13). The intuition for this is that the distribution of

<sup>17</sup>The correlation between the aggregate growth rate of capital for this subsample and the same measure for the balanced panel amounts to 0.89.



firms' mandated capital adjustments is centered at the flat part of the adjustment function during this time. In this region of the adjustment function firms are unwilling to respond to changes in investment incentives, due to e.g. binding irreversibility constraints.

An implication is e.g. that monetary policy seems to be relatively powerless in stimulating the economy during recessions, whereas it can effectively cool off an overheated economy. It should be noted that this conclusion is based on a partial experiment where the central banks policy instrument, the interest rate, directly affects the user cost of capital which in turn affects the distribution of firms mandated capital adjustment.

## 7 Conclusions

The objective of this paper was to present a series of stylized facts on the capital accumulation patterns for Swedish manufacturing firms and to relate the empirical findings to standard models of firm behavior in the presence of impediments to capital adjustments. To this end we use an integrated approach, i.e. we compare the predictions of different investment models to the observed patterns in the data both within (rank and timing patterns of the growth rate of capital) and between (distribution of the growth rate of capital) firms. Furthermore, we also apply a more direct approach and estimate an adjustment function relating capital adjustment to the difference between desired and actual capital stock.

We show that the partial adjustment model generally fails to explain capital adjustment patterns and that a S,s model only succeeds to replicate the stylized features of the data within but not between firms. The trigger points of the simulated S,s model suggest that firms' adjustment behavior is asymmetric in that they are more likely to tolerate excess capital than shortages of capital. Moreover, it is interesting to see that the trigger levels are close to what one would set them to in order to mimic an irreversibility constraint. However, the irreversibility model yields a adjustment pattern that is similar to the S,s model in the within-firm dimension but not in the between-firm dimension where it fits the data better than the S,s model does. We also decompose the cyclical pattern of growth rates of capital and find that large capital adjustments of relatively few firms seem to be an important

determinant of aggregate changes.

In the second part of the paper we show that the estimated adjustment function is upward sloping, supporting the notion that the approach does capture investment incentives. The adjustment function suggests an asymmetric response to capital surpluses and capital shortages; firms seem to be less responsive to capital surpluses relative to capital shortages on average. When we connect the first and second part of the paper by relating the empirical adjustment function to the adjustment functions that is implied by the standard models of firm behavior we find that irreversibility seems to provide a better description of firm behavior when mandated capital adjustment is negative. For positive values we see that the empirical adjustment function is flatter than what is implied by any of the adjustment models studied in this paper. This may be due to measurement errors or financial constraints.

We close the paper by examining whether the results from the previous sections are important for our understanding of the behavior of aggregate capital accumulation. The results indicates that not allowing for nonlinearity in the adjustment function, i.e. by assuming convex adjustment costs, would be misleading. We find especially large effects of nonlinearity on the responsiveness of aggregate capital growth in times with low economic activity. In the midst of the recession in the beginning of the 1990s the responsiveness was only about half of its average in normal times.

The overall conclusion is that none of the models are perfect in the sense that they could reproduce the patterns in the data in all dimensions that we have studied, but a clear element of irreversibility is found in the data. A policy implication from this is that monetary policy seems to be relatively powerless in stimulating the economy during recessions, whereas it can effectively cool off an overheated economy.

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## 8 Appendix A - Data

The data used in this paper are extracted from the CoSta database, described in Hansen (1999). The sample of firms was first selected as follows:

- Only firms classified within industries 31-38 according to the SNI69 classification system, i.e. the manufacturing sector, is included.
- Only firms that are ongoing throughout the sample period are included (to obtain a balanced panel).
- Only firms that are classified as an ordinary company and as an identical/comparable firm from last year in all years are included.

The variables are defined below in terms of those in the CoSta database (see Hansen 1999).

Output  $Y_{i,t} = Var005_{i,t}/PPI_{i,t}$ , where  $Var005$  is operating income and  $PPI$  is a three-digit industry-specific producer price index supplied by Statistics Sweden. For industries where a three-digit producer price index is missing a two-digit producer price index is used instead.

The Stock of Capital  $K_{i,t}$  is the stock of machinery and equipment generated using the perpetual inventory method, i.e.:

$$K_{i,t} = (1 - \delta_i)K_{i,t-1} + I_{i,t}, \quad (26)$$

where  $\delta_i$  is the depreciation rate and  $I_{i,t}$  is investments in machinery and equipment. When calculating three digit depreciation rates for machinery and equipment the estimated industry specific service lives ( $SL_i$ ) are taken from the BEA publication "Fixed Reproducible Tangible Wealth In the United States, 1925-89" and the estimated declining balance rate ( $DBR$ ) for machinery and equipment, assumed to be equal for all manufacturing industries (1.65), is taken from the BEA publication "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929-1995" by Katz & Herman (1997). The depreciation rate is then calculated as  $\delta_i = DBR/SL_i$ . Unfortunately, in most cases we must resort to an estimate of the

service life for two-digit industries. Investments is defined as  $I_{i,t} = (Var115_{i,t} + Var119_{i,t} - Var127_{i,t})/IPI_{i,t}$ , where  $IPI$  is the two-digit investment deflator compiled from investment series for machinery and equipment in current and fixed prices collected from SM series N, Statistics Sweden. As starting value for the stock of capital the value according to plan of machinery and equipment ( $Var146_{i,1979}$ ) deflated by  $IPI_{i,1979}$  is used.

The Real User Cost of Capital  $C_{i,t}$  is defined as in Dufwenberg et al. (1994), i.e.:

$$C_{i,t} = \frac{IPI_{i,t}}{PPI_{i,t}} \left[ \frac{1 - \Theta_t}{1 - \tau_t} \rho_t + \delta_i - \frac{\Delta IPI_{i,t}}{IPI_{i,t-1}} \right], \quad (27)$$

where  $\tau_t$  is the corporate tax rate,  $\rho_t$  is the firms discount rate (assuming a debt to capital ratio of 0.4 and the shareholders after tax required rate of return is equal to 1.5 times the yield on long term industrial bonds) and  $\Theta_t$  is the present discounted value of tax savings from depreciation allowances, investment grants, etc. per unit of investment. The series for  $\tau_t$ ,  $\rho_t$  and  $\Theta_t$  has kindly been provided by Prof. Jan Södersten.

For the firm to be included in the sample we also require it to have a stock of capital and capital expenditures, i.e. ( $Var115_{i,t} + Var119_{i,t}$ ), and a market value of sold machinery and equipment, i.e.  $Var127$ , that are non-negative in all time periods. This leaves us with a sample of 341 firms. Finally, to mitigate the effect of the initial assumption for the capital stock we only use the 1984-1994 observations.

## 9 Appendix B - Results from Size Quartiles

To study if the size of the firm is an important determinant for the shape of the capital adjustment pattern, e.g. due to indivisibility, we splitted the sample into size quartiles after the average number of employees.<sup>18</sup> To guarantee the exogeneity of the selection criterion we use the average number of employees over the years 1979-1982 as a criterion of separation. The pattern in the tables (1) and (2) is consistent with the indivisibility argument, i.e. that small firms are forced to discrete adjustments. However, all quartiles share the same general pattern.

Table 1: Mean GK for employment size quartiles

<i>Rank</i>	<i>Q1</i>	<i>Q2</i>	<i>Q3</i>	<i>Q4</i>	<i>Total</i>
1	0.6904	0.6192	0.5151	0.4681	0.5741
2	0.2981	0.2853	0.2624	0.2117	0.2646
3	0.1821	0.1884	0.1686	0.1399	0.1700
4	0.1091	0.1205	0.1077	0.0971	0.1088
5	0.0657	0.0778	0.0727	0.0642	0.0702
6	0.0274	0.0435	0.0455	0.0381	0.0387
7	0.0258	0.0204	0.0175	0.0119	0.0132
8	-0.0203	-0.0061	-0.0074	-0.0029	-0.0091
9	-0.0428	-0.0315	-0.0266	-0.0219	-0.0307
10	-0.0664	-0.055	-0.0471	-0.0465	-0.0538
11	-0.1061	-0.0935	-0.0907	-0.0880	-0.0946

<sup>18</sup>Q1:  $n$  (the average number of employees)  $\leq 58$ , Q2:  $58 < n \leq 89.4$ , Q3:  $89.4 < n \leq 178.2$ , Q4:  $n > 178.2$ .

Table 2: Mean within firm timing pattern (Mean GK)

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	$t - 2$	$t - 1$	$t$	$t + 1$	$t + 2$
<i>Q1</i>	0.0746	0.0718	0.6904	0.0571	0.0714
<i>Q2</i>	0.0780	0.1106	0.6192	0.0782	0.0419
<i>Q3</i>	0.0625	0.102	0.5151	0.0903	0.0589
<i>Q4</i>	0.0480	0.0574	0.4681	0.0752	0.0491
<i>Total</i>	0.0658	0.0859	0.5741	0.0755	0.0549

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## 10 Appendix C - Growth Rate of Investment

Since the growth rates of capital studied above involves at least two assumptions it is interesting to study the capital adjustment behavior in the investment dimension. In figure 8 we have plotted the mean shares of total 11-year investment by rank.

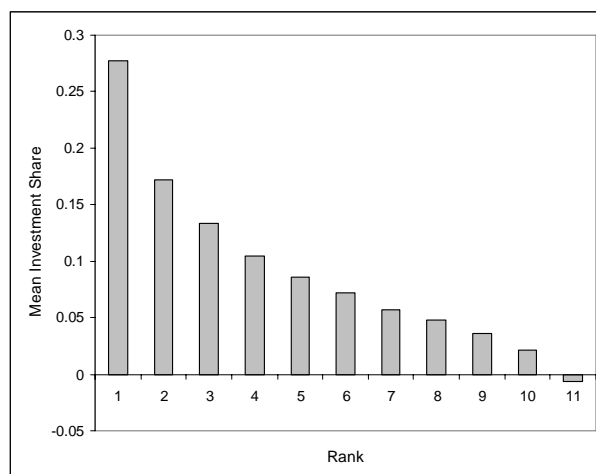


Figure 8: Mean investment shares by capital growth rate rank.

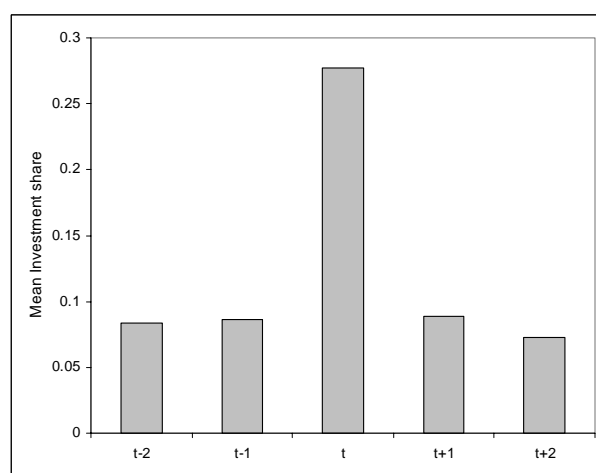


Figure 9: Mean pre- and post-spike investment growth rates.

As can be seen in figure 8, about 60 percent of the total investment volume during the

period is carried out in only three years on average. Moreover, when looking at the timing of the investments as shown in figure 9 we see the same pattern emerges as when studying growth rates. This is interesting since we can be somewhat more confident that the patterns described throughout this paper are not an artifact of our assumption of how capital evolves over time.

## 11 Appendix D - Unbalanced Panel

To investigate whether our selection of only ongoing firms is driving our results, we have also experimented with an unbalanced panel. To obtain our unbalanced panel we follow the cleaning procedure as described in Appendix A, but we only require the firms to be observed seven consecutive years. This gives us a sample of 2321 firms. The reason for only using firms observed seven or more years in a sequence is that we need to calculate capital stocks, and since we drop the first four observations to mitigate the initial value problem we are left with at least three observations for each firm. Then, since lagged values of capital are used, we effectively have two observations for each firm - which is the minimum number of observations needed to estimate the firm specific constant for each firm.

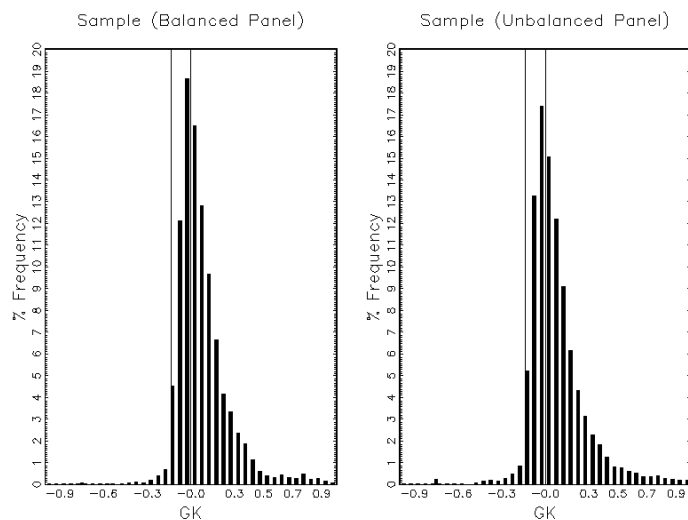


Figure 10: Density of the growth rates of capital for the unbalanced sample.

As can be seen in figure 10 the distribution of the growth rates for the unbalanced panel is very similar to the distribution of the balanced panel. Thus, figure 10 does not lend any evidence of the hypothesis that the results are biased in favor of finding irreversibility due to our sample selection.

In figure 11 the adjustment function for the unbalanced sample is presented. This adjustment function is similar to the one obtained from the balanced sample. The only difference

is that the value for the top intervals is somewhat higher for the unbalanced panel. However, this difference do not give rise to any qualitaively different results for the aggregate responsiveness to aggregate shocks, as can be seen in figure 12. The aggregate responsiveness is estimated in the same way as for the balanced panel. However, the reponsivness in this case is also affected by changes in the population over time. Overall, the results from the unbalanced panel does not indicate that sample selection is not a crucial issue here.

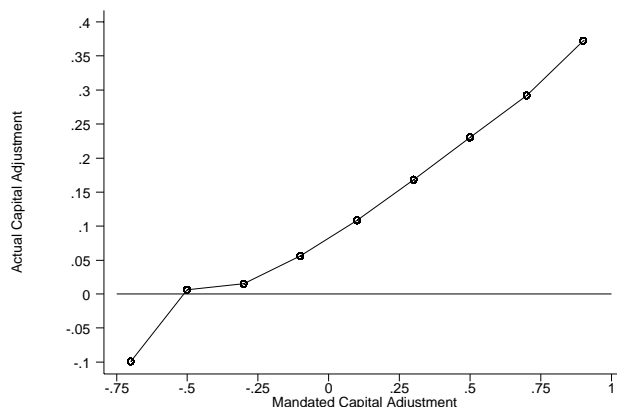


Figure 11: Empirical adjustment function, i.e. the averages of actual adjustment,  $GK_{i,t}$ , over nine intervals defined on  $m^p \in [-0.8, 1]$  for the unbalanced panel.

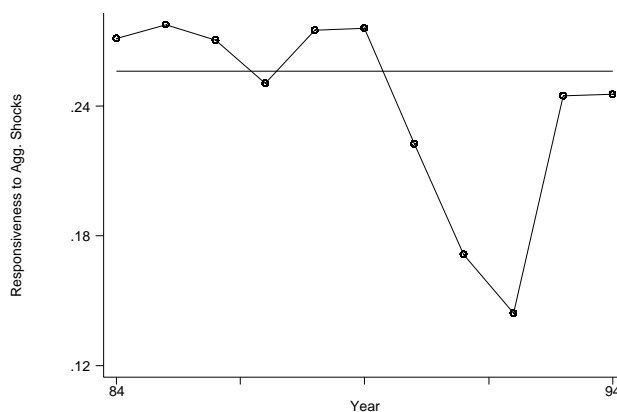


Figure 12: Responsiveness of aggregate capital growth to aggregate shocks ( $\partial GK_{A,t} / \partial m_t^p$ ) for the unbalanced panel.

## 12 Appendix E - Measurement errors

In this appendix we make an attempt to evaluate the effects of classical measurement errors in our measure of mandated capital adjustment. For clarity we restate equation (19);

$$m_{i,t} = \eta [y_{i,t} - k_{i,t-1} - c_{i,t} + v_i]. \quad (19)$$

Since the variables on the right hand side of (19) might be measured with error it obviously follows that  $m_{i,t}$  may also be measured with an error. Here we try to control for this error by using the first lag of  $m_{i,t}$  as an instrument for  $m_{i,t}$ . Given that we only try to control for classical measurement errors, lags should be a valid instrument. However, a strong caveat should be mentioned at this point. The relevance of the instrument we use hinges crucially on the true underlying adjustment process. If the firms reduces the deviation between the desired and the actual stock of capital with a fraction each period due to a symmetric convex adjustment cost, this instrument should be highly relevant. However, on the other extreme, if the firms adjust completely in each period the instrument would have no relevance what so ever. Between these extremes we might also have asymmetric relevance. For example, if an irreversibility constraint drives the adjustment behavior, the relevance of lagged mandated capital adjustments as an instrument for current mandated capital adjustments depends on whether  $m_{i,t-1}$  is strongly negative or not. With these considerations in mind, we continue by estimating the adjustment function applying the non-parametric estimator described in the main text by replacing  $m_{i,t}$  with the prediction of  $m_{i,t}$  estimated using the following specification,

$$m_{i,t} = a_{0,i} + a_{1,i}m_{i,t-1} + e_{i,t}, \quad (28)$$

where  $a_0$  and  $a_1$  are firm specific parameters estimated for each firm in the balanced panel. Note that we lose one observation for each firm relative to the sample used in the main text.

In figure 13 (dashed line) the resulting adjustment function is depicted for the relevant intervals, i.e. intervals containing at least 30 observations. In figure 13 we have also plotted the adjustment function without correcting for measurement error we obtain using the same sample as when correcting for the measurement error. When comparing the adjustment

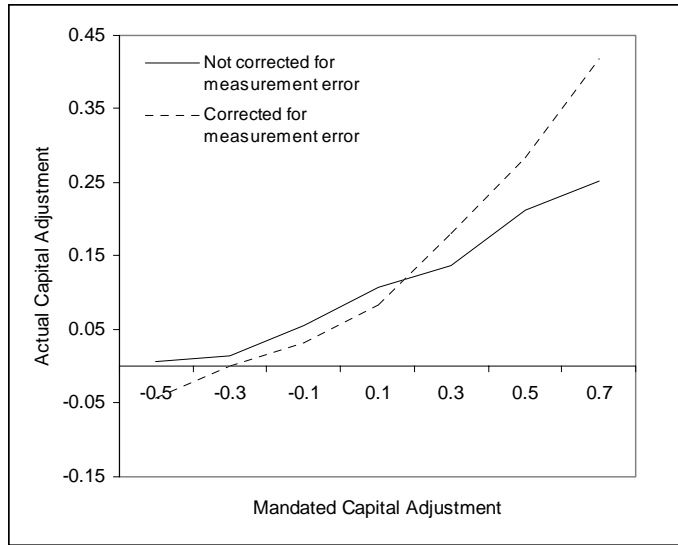


Figure 13: Empirical adjustment function corrected (dashed line) and not corrected (solid line) for measurement error in  $m_{i,t}^p$ .

functions we see that the slope of the adjustment function increases when we correct for measurement errors. This is expected since classical measurement errors tend to attenuate slope parameters. One can also see that the asymmetry in the adjustment behavior between positive and negative mandated capital adjustment is more pronounced when correcting for measurement errors.

Finally, we check if the behavior of the responsiveness of aggregate capital growth to aggregate shocks is affected by measurement errors. This is done by using the same approach as described in the main text. Since we only have limited information about the adjustment function for values of mandated capital adjustments outside the interval  $-0.6$  to  $0.8$  (when controlling for measurement errors), we restrict our attention to firms with a  $m_{i,t}^p \in [-0.6, 0.8]$  in all periods. This leaves us with a sample of 192 firms.

In figure 14 the responsiveness for aggregate capital growth to aggregate shocks when controlling for measurement errors is depicted by year. In figure 15 we have plotted the analogous results when not correcting for measurement errors. As in the main text, the straight lines in figures 14 and 15 depict the responsiveness of aggregate capital growth

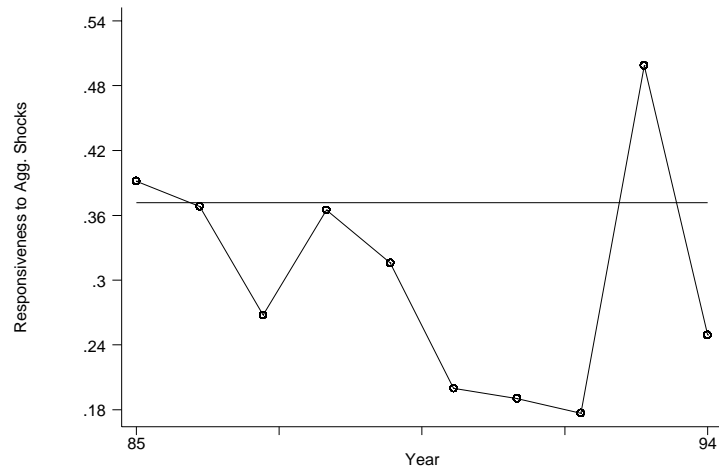


Figure 14: Responsiveness of aggregate capital growth to aggregate shocks per year when correcting for measurement errors in  $m_{i,t}^p$ .

to aggregate shocks if the adjustment function would be linear. Although the level of the estimated responsiveness is shifted upwards when controlling for measurement errors, the behavior of the responsiveness over time is similar to what we find when we do not control for measurement errors.

Overall, controlling for measurement errors do not seem to change our conclusions qualitatively. However, one should keep the caveats above in mind.

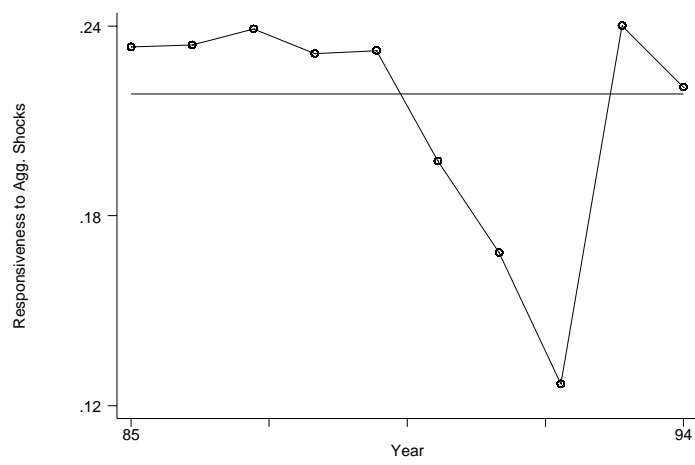


Figure 15: Responsiveness of aggregate capital growth to aggregate shocks per year not correcting for measurement errors in  $m_{i,t}^p$ .