Firm-level adjustment costs and aggregate investment dynamics

Estimation on Hungarian data

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Abstract: This paper uses Hungarian data to estimate the structural parameters of a firm-level investment model with a rich structure of adjustment costs, and analyzes whether non-convex adjustment costs have any effect on the aggregate investment dynamics. The main question addressed is whether aggregate profitability shocks (as a result of monetary policy, for example) lead to different aggregate investment dynamics under non-convex and convex adjustment costs. The main finding is that while non-convex adjustment costs make investment lumpier at the firm level, they lead to a more flexible adjustment pattern at the aggregate level. This can be explained by the fact that if replacement investment is relatively cheap, the proportion of non-adjusting firms (i.e. firms that engage only in replacement investment) is similar under convex and non-convex adjustment costs, while the average size of new investment of active firms is higher under non-convex adjustment costs.

1. Introduction

In Hungary, corporate investment behavior has been mainly investigated on aggregate data (see, for example, *Darvas-Simon, 2000*, and *Pula, 2003*), and only few studies follow the new international trend of addressing this question at the firm level. Among these few studies, *Molnár-Skultéty (1999)* used the 1996 wave of the investment statistics survey of the Hungarian Central Statistical Office[1] to characterize the corporate investment behavior by such factors as size of investment costs, number of employees, sales revenues, and to make a correlation analysis of investment activity with various balance sheet measures. In another study, *Szanyi (1998)* uses a PHARE-ACE investment survey[2] to investigate the dynamics of investment activity, and reports the evolution of some simple descriptive statistics (investment relative to sales revenues and number of employees) between 1992-1995. Finally, *Kátay-Wolf (2004)* use the Hungarian Tax Agency's balance sheet data of all double entry book keeping firms between 1992-2002, and make a step beyond providing simple descriptive statistics of firm-level corporate investment behavior by addressing the question of how „changes in the user cost of capital – of which the interest rate is only a determinant – affect corporate investment behavior"[3] with econometric tools.

This paper is a follow-up of the analysis of *Kátay-Wolf (2004)* in the sense that (1) it investigates the determinants of the investment behavior at the firm level; and (2) uses the same data set. However, there are several aspects according to which my approach is somewhat different:

(1) As a modeling framework I use the "new investment models" set up by the post-1990 investment literature, incorporating those characteristics of firm-level investment behavior that we have overwhelming empirical evidence about.[4] The main focus of these models is on different types of firm-level investment costs, which include fixed, convex, irreversibility and disruption costs that firms may have to pay when undertaking investment.[5]

(2) Another difference of my approach is that while in *Kátay-Wolf (2004)* the main driving force of investment is the appropriately defined "user cost of capital", I use a model in which one does not claim to know exactly which factors affect investment activity and which do not, but there is a "profitability shock" (that incorporates any influencing factor) which is the main determinant of investment at the firm level. As a consequence, much emphasis is taken on the empirical identification of this profitability shock and its distribution.

(3) Most importantly, I extend the framework to investigate aggregate investment behavior, where aggregate investment is defined simply as the sum of firm-level behaviors.

So *the ultimate goal of this paper is to answer the question of how monetary policy can affect aggregate investment.* In doing so, I assume that monetary policy affects the aggregate profitability shock that hits the firms, and the sum of the firm-level responses to this

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[1] This survey contains all corporate investment activity that exceeded 10 million HUF-s in 1996 prices.
[2] Here data is available about 258 firms that voluntarily filled a questionnaire about their investment behavior between 1992-95. The data set is admittedly non representative.
[3] *Kátay-Wolf (2004)*, p. 2.
[4] Two influential empirical papers are *Doms-Dunne (1998)* about lumpiness, and *Ramey-Shapiro (2001)* about irreversibility. These phenomena are incorporated into the theoretical investment models by *Abel-Eberly (1994)* and *Bertola-Caballero (1994)*, for example.
[5] See *Stokey (2001)* for a taxonomy about these types of costs. For empirical estimation of the different cost components, see *Bayraktar et al. (2005)* and *Cooper-Haltiwanger (2005)*.

aggregate profitability shock will determine the effect of monetary policy on aggregate investment.

The paper is organized as follows. Section 2 describes the model, and Section 3 discusses estimation strategy. A more detailed description of these can be found in *Reiff (2006)*. Section 4 is about the data and the main variables, while Section 5 presents the firm-level results. Section 6 is about the estimated cost parameters and their discussion, and Section 7 contains the aggregate implications. Section 8 concludes.

2. Model

Let us consider a general investment model, in which firms maximize the present value of their future profits, net of future investment costs:[6]

$$V(A_0, K_0) = \max_{\{I_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\Pi(A_t, K_t) - C(I_t, K_t) \right] \right\}, \tag{1}$$

where profit at time *t* is given by $\Pi(A_t, K_t)$, with A_t and K_t denoting profitability shock and capital stock at time t, respectively,[7] the cost of investment I_t is $C(I_t, K_t)$, and β is a discount factor. The capital stock depreciates at a rate of $\delta > 0$, and the profitability shock is assumed to be a first-order Markov-process, so the transition equations are

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{2}$$

$$A_{t+1} | A_t \text{ is a random variable with known distribution.} \tag{3}$$

Firms then maximize (1) with constraints (2) and (3). Omitting time indices, and denoting next period's values by primes, the solution entails solving the following maximization problem in each time period:

$$\max_I \left\{ -C(I, K) + \beta E_{A'|A} V\left(A', K' = (1-\delta)K + I | A\right) \right\}, \qquad (4)^8$$

and the solution is

[6] The general structure of this model is similar to the models presented by *Abel and Eberly (1994)* and *Stokey (2001)*.

[7] The "profitability shock" and the $\Pi(A_t, K_t)$ profit function will be defined explicitly later.

[8] More precisely, the resulting value function is given by the Bellman equation

$$V(A, K) = \max_I \left\{ \Pi(A, K) - C(I, K) + E_{A'|A} V(A', K' | A) \right\}$$

$$\beta E_{A'|A} \frac{\partial V(A',K')}{\partial K} = \beta E_{A'|A} V_K(A',K') = C_I(I,K).^9 \tag{5}$$

This is a well-known optimum condition, stating that the (expected) discounted marginal value of capital (left-hand side) should be equal to the marginal cost of capital (right-hand side).

So the timing of the model is the following: firms have an initial capital stock K, and then they learn the value of the profitability shock A. This influences the expected discounted marginal value of capital (left-hand side of (5)). Finally, firms choose I to make the marginal cost (right-hand side) equal to the marginal value of capital (taking into account that the choice of I also influences the marginal value of capital through K'), and enter the next period with their new capital stock K'. In the rest of the paper I describe this sequence of events with the "investment-shock relationship": in each time period, firms respond to profitability shock A with an optimal investment rate I or $I^*(A)$.

Obviously, the solution in (5) depends crucially on the exact formulation of the cost function. In this paper I use a general formulation of the investment cost function $C(I_t, K_t)$ with three types of cost components.

The first component of the investment cost function is the fixed cost F, which has to be paid whenever investment is non-zero:[10]

$$C(I,K) = \begin{cases} F + \Gamma(I,K), I \neq 0. \\ 0, I = 0. \end{cases} \tag{6}$$

where $\Gamma(I,K)$ is the cost of investment other than fixed costs (time indices are dropped once again).

The second component of the investment cost function is a linear term, which represents the buying (*P*) and selling (*p*) price of capital $(P \geq p \geq 0)$. Thus $\Gamma(I,K)$ can be further divided as

$$\Gamma(I,K) = \begin{cases} PI + \gamma(I,K), I \geq 0. \\ pI + \gamma(I,K), I < 0. \end{cases} \tag{7}$$

Finally, the third component of the investment cost function is $\gamma(I,K)$, which is the usual convex adjustment cost; I assume that $\gamma(I,K)$ is a parabola-like function, with a

[9] V_K is the marginal value of capital for the firm, often denoted by *q* (Tobin's marginal *q*).

[10] This fixed cost is assumed to be independent from I, but not necessarily from K. In fact it is a common assumption in the literature that the investment cost function is homogenous of degree 1 in (I,K), and therefore the fixed cost is assumed to be proportional to K. To ease exposition, for the time being I simply write F instead of FK.

minimum value of 0, and also a possible kink at $I=0$.[11] Therefore the partial derivative of this function with respect to *I* is non-decreasing, with negative values for $I<0$ and positive values for $I>0$, and this derivative may be discontinuous at $I=0$ if and only if there is a kink in the $\gamma(I,K)$ function there.

More specifically, I define the fixed component of the investment cost function as FK, and the convex component as $\gamma(I,K)=\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K$, so that the investment cost function is linearly homogenous in (I,K). I normalize the model to the buying cost of capital, and assume that $P=1$, from which it follows that for the selling cost of capital $0\le p\le 1$ must hold.[12]

Additionally, I will also distinguish between replacement investment and new investment. This generalization of the usual investment models in literature is introduced extensively discussed in *Reiff (2006)*. There are several reasons why replacement investment is not as costly as new investment: (1) when undertaking replacement investment, firms often have their tools and machines checked, certain parts exchanged or upgraded, and this entails contacting well-known suppliers at much lower costs; (2) learning costs are also likely to be much lower in this case. Though replacement investment may also entail adjustment costs, it seems to be a reasonable approximation to treat replacement investment cost-free, as opposed to costly new investment. Specifically, I assume that investments up to the size of δK (the depreciated part of capital) have no convex or fixed costs, and firms have to pay adjustment costs after that part of investment that exceeds this amount. Of course, when undertaking replacement investment, firms still have to pay the unit purchase price of investment goods.

Thus the final specification of the investment cost function is the following:

$$\frac{C(I,K)}{K}=\begin{cases} \frac{I}{K}, 0\le\frac{I}{K}\le\delta, \\ F+\frac{I}{K}+\frac{\gamma}{2}\left(\frac{I-\delta K}{K}\right)^2, \frac{I}{K}>\delta, \\ F+p\frac{I}{K}+\frac{\gamma}{2}\left(\frac{I}{K}\right)^2, \frac{I}{K}<0. \end{cases} \tag{8}$$

To conclude this section, I discuss the effects of the different cost components on the investment behavior of the individual firms. For this, I will use the "investment-shock relationship", which describes how firms optimally react (in terms of investment rate) to different profitability shocks.[13]

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[11] Specifically, $\gamma(I,K)=0$ is assumed to be twice continuously differentiable except possibly at $I=0$, weakly convex, non-decreasing in $|I|$, with $\gamma(0,K)=0$.

[12] So if $p=1$, then there is no irreversibility. Complete irreversibility will be characterized by $p=0$.

[13] Besides the "timing of the model" argument discussed earlier, this investment-shock relationship can be motivated also by the following line of arguments. We can say that in the dynamic optimization problem defined above, one can derive the policy function of the firms: optimal investment as a function of initial profitability shock (*A*) and capital (*K*) $I^*=g(A,K)$. This is almost equivalent to writing $I^*/K=g(A)$.

Because of *fixed costs*, firms will never make small adjustments for which the net gain of adjustment would not compensate for the fixed costs. This means that for small shocks firms remain inactive, but for larger shocks firms make large adjustments; so fixed costs lead to inaction and discontinuity of the investment-shock relationship.

Irreversibility costs lead to inaction by making negative adjustments more expensive: for small negative shocks, firms will still hold on with their initial level of capital, and – in the hope of more favorable future shocks – do not take on the irreversibility cost. For larger negative shocks, firms may end up selling capital, but as irreversibility costs are proportional to the amount sold, the amount sold increases only gradually with the size of the negative shock. Therefore irreversibility also causes inaction, but does not lead to discontinuity in the investment-shock relationship.

Finally, as in well-known traditional models, *convex costs* leave the investment-shock relationship smooth, but make it flatter (i.e. investment becomes less responsive to shocks) by making capital adjustment more expensive.

To graphically demonstrate these effects of the different cost components, I solved the theoretical model for various simple cases when there is only one type of investment cost, with the purpose of comparing the resulting investment-shock relationships with the investment-shock relationship in the frictionless case (see *Appendix*).

3. Estimation strategy

To estimate the structural cost parameters of the model, I use a modified version of the indirect inference method.[14] The philosophy of this approach is that first we select some empirically observable statistics (this can be a regression equation or any other descriptive statistics) that are all influenced by the structural parameters of the model, and then the estimated parameters will be obtained by matching the theoretical counterparts of the selected statistics to the observed ones.

The most important step when using indirect inference is the appropriate choice of those statistics according to which we match the theoretical model to what is observed empirically. As discussed in length by *Reiff (2006)*, the following set of statistics is appropriate to estimate the structural cost parameters of the model:

(1) A quadratic reduced-form shock-investment relationship:

$$\tilde{i}_{it} = \phi_0 + \phi_1 \tilde{a}_{it} + \phi_2 \tilde{a}_{it}^2 + \phi_3 \tilde{a}_{i,t-1} + \mu_t + u_{it} , \qquad (9)$$

where i denotes investment rate, a denotes (log) profitability shock, μ_t is a time-dummy, u is a well-behaving error term, and the variables with tildes denote deviations from plant-specific means. In this specification the parameter ϕ_2 is meant to capture the discontinuity- and the inaction-caused non-linearity of the investment-shock relationship (because of discontinuity and/or inaction, higher profitability shocks lead to proportionally higher investment activity), while parameter ϕ_3

[14] This estimation technique was first described by *Gourieroux-Monfort (1993)*.

represents the lumpiness of investment (because of inaction, investment reacts to shocks sometimes with a lag).

(2) The proportion of inactive observations (the "inaction rate") in the investment rate distribution.[15]

(3) The skewness of the distribution if firm-level investment rates.

Therefore, to estimate the parameters of the investment cost function, I first estimate these parameters from data; denote the vector of these observed values by ϕ_0. Then I simulate the theoretical model for arbitrary cost parameters to obtain the estimates of the same parameters from the theoretical model (that is, obtain $\hat{\phi}(F,\gamma,p)$). Finally, I choose those cost parameters for which the distance between the observed and simulated parameters is the smallest: I minimize $\left(\phi_0-\hat{\phi}(F,\gamma,p)\right)' W^{-1}\left(\phi_0-\hat{\phi}(F,\gamma,p)\right)$ with respect to (F,γ,p).[16]

4. Data and variables

I use the data set of *Kátay-Wolf (2004)*: "corporate tax returns of double entry book keeping firms between 1992 and 2002"[17] in Hungary, with the only exception that I use only the manufacturing sub-sample. This is to eliminate huge inter-sectoral heterogeneities in the investment costs. Otherwise, the initial data filtering is the same, and in fact in most cases I simply adopted the variables of *Kátay-Wolf (2004)*.

As it is important to know the aspects of the sample construction, let me briefly summarize the steps of initial data manipulation in *Kátay-Wolf (2004)*:

(1) observations with relevant missing data (number of employees, capital depreciation) were deleted;

(2) very small firms[18] were deleted;

(3) data were corrected when it was considered false;

(4) outliers (with respect to cash-flow, depreciation rate, user cost, investment rate, changes in capital stock, employment, sales, user cost) were excluded.

As a result of this, the original panel of 1,269,527 year-observations was reduced by *Kátay-Wolf (2004)* to 308,850 year-observations. Since I estimate the cost parameters only on manufacturing firms, the size of the sample further reduced to 110,808 year-observations. Also, I went on with the exclusion of missing observations and outliers with respect to my key variables (investment rate, sales revenue, capital stock, profit), so the final sample size of my data set is 92,293 year-observations.[19]

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[15] *Appendix C* shows why matching the proportion of inactive observations and skewness is essential to identify all types of cost components.

[16] Here the weighting matrix W^{-1} is the variance-covariance matrix of the estimated ϕ_0, so any statistics that is estimated with higher precision (i.e. smaller standard error) gets higher weight.

[17] *Kátay-Wolf (2004)*, p. 28. The 1992 wave of the tax returns is excluded later because of low reliability and missing investment rate data, so effectively the panel starts in 1993 and ends in 2002.

[18] Definition of very small firms: if the number of employees is smaller than 2 in a particular year, or if the number of employees is smaller than five during three consecutive years.

[19] Specifically, I deleted 18,308 year-observations because of missing investment rate. (These were mostly the observations of 1992, when initial capital stock was not available.) Then I deleted further 118 year-observations

The key variables in this paper are investment rate, capital and profit. To measure *gross investment rate*, I simply adopt the investment rate variable used in *Kátay-Wolf (2004)*, who constructed investment rates from accounting capital data. From the calculated gross investment levels and observed depreciations, *Kátay-Wolf (2004)* constructed a real *capital variable* with Perpetual Inventory Method (PIM); I use this variable to measure capital stock. Finally, I use *operating profit* to measure the profit of the firms.

5. Empirical results at the firm-level

In this section I describe how to estimate empirically those statistics (already listed in Section 3) that will be used to identify the structural cost parameters. These are the estimated parameters of the reduced form shock-investment relationship (9), the proportion of inactive firms and the skewness of the investment rate distribution.

For the reduced-form shock-investment relationship, it is necessary to have a profitability shock and an investment rate variable. This latter variable will also be used to determine the inaction rate and the investment rate distribution skewness. In what follows, I first describe the identification of the profitability shocks, then discuss the measurement of new investment rates, and finally present the estimated parameters and statistics (to which matching will be done).

5.1. Identification of profitability shocks

I use the method described by *Cooper-Haltiwanger (2005)* to identify the profitability shocks. Assume that firms have identical, constant returns-to-scale Cobb-Douglas production functions:[20]

$$Y_{it} = B_{it} L_{it}^{\alpha_L} K_{it}^{1-\alpha_L} , \tag{10}$$

where labor (L_{it}) can be adjusted in the short-run and can therefore be regarded in the yearly sample as being optimized, but capital (K_{it}) cannot be adjusted in the short-run. Y_{it} denotes production, B_{it} is production shock,[21] α_L is labor share. I also assume that firms face a constant elasticity (ξ) demand curve $D(p) = p^{\xi}$, so the inverse demand curve is $p(y) = y^{1/\xi}$. Therefore the firms' problem is:

because of non-positive sales revenues. Next, I deleted those 35 year-observations for which capital stock was missing. Finally, I deleted 54 year-observations with unobserved profit. These steps reduced the sample size to 110,808 – 18,308 – 118 – 35 – 54 = 92,293 year-observations.

[20] It is not necessary to assume constant returns to scale; the same line of arguments could be made if we had a capital share $\alpha_K \neq 1-\alpha_L$.

[21] This production shock is not the profitability shock that we have in reduced regression (9).

$$\Pi_{it} = p_{it}(y_{it})y_{it} - w_{it}L_{it} = y_{it}^{\frac{1+\xi}{\xi}} - w_{it}L_{it} = B_{it}^{\frac{1+\xi}{\xi}} L_{it}^{\alpha_L\frac{1+\xi}{\xi}} K_{it}^{(1-\alpha_L)\frac{1+\xi}{\xi}} - w_{it}L_{it} \xrightarrow[L_{it}]{} \max, \tag{11}$$

where w_{it} stands for wage rate. The first-order condition of this problem is $\alpha_L \frac{1+\xi}{\xi} B_{it}^{\frac{1+\xi}{\xi}} K_{it}^{(1-\alpha_L)\frac{1+\xi}{\xi}} L_{it}^{\alpha_L\frac{1+\xi}{\xi}-1} = w_{it}$, from which the optimal labor usage is

$$L_{it}^{*} = \left(\frac{\xi}{\alpha_L(1+\xi)}\right)^{\frac{\xi}{\alpha_L(1+\xi)-\xi}} w_{it}^{\frac{\xi}{\alpha_L(1+\xi)-\xi}} B_{it}^{\frac{1+\xi}{\xi-\alpha_L(1+\xi)}} K_{it}^{\frac{(1+\xi)(1-\alpha_L)}{\xi-\alpha_L(1+\xi)}}. \tag{12}$$

Substituting this into the profit function (11), the optimal profit of the firm is

$$\Pi_{it}^{*} = B_{it}^{\frac{1+\xi}{\xi}} \left(L_{it}^{*}\right)^{\alpha_L\frac{1+\xi}{\xi}} K_{it}^{(1-\alpha_L)\frac{1+\xi}{\xi}} - w_{it}L_{it}^{*} =$$

$$= \left(\frac{\xi}{\alpha_L(1+\xi)}\right)^{\frac{-\xi}{\xi-\alpha_L(1+\xi)}} w_{it}^{\frac{-\alpha_L(1+\xi)}{\xi-\alpha_L(1+\xi)}} B_{it}^{\frac{1+\xi}{\xi-\alpha_L(1+\xi)}} K_{it}^{\frac{(1+\xi)(1-\alpha_L)}{\xi-\alpha_L(1+\xi)}} \left[\frac{\xi}{\alpha_L(1+\xi)} - 1\right]. \tag{13}$$

Hence if we write (13) as $\Pi_{it}^{*} = A_{it}K_{it}^{\theta}$, where A_{it} denotes the profitability shock,[22] then $\theta = \frac{(1+\xi)(1-\alpha_L)}{\xi-\alpha_L(1+\xi)}$, a function of the demand elasticity and the labor share in the production function.

I identify firm-level profitability shocks simply by $A_{it} = \frac{\Pi_{it}^{*}}{K_{it}^{\theta}}$, which can be calculated from the data set once we have an estimate for θ. I will return to the estimation of θ later.

I call the profitability shock calculated this way as type 1 shock. But this measurement contains observed profits, which appears to be highly unreliable in many studies, so I use an alternative method to identify the profitability shocks. A little algebra shows that the optimal profit in (13) can also be written as

$$\Pi_{it}^{*} = w_{it}L_{it}^{*}\left[\frac{\xi}{\alpha_L(1+\xi)} - 1\right] = w_{it}L_{it}^{*}\frac{1}{\theta}\frac{1-\alpha_L}{\alpha_L}, \tag{14}$$

therefore the A_{it} profitability shock can also be calculated as

[22] Note that the profitability shock consists of wages, demand elasticities, labor shares and productivity shocks.

$$A_{it} = \frac{\Pi_{it}^*}{K_{it}^\theta} = \frac{w_{it} L_{it}^* (\xi - \alpha_L (1+\xi))}{K_{it}^\theta \alpha_L (1+\xi)} = \frac{w_{it} L_{it}^*}{\theta K_{it}^\theta} \frac{1-\alpha_L}{\alpha_L}. \tag{15}$$

To compute the profitability shock this way, one should know the value of α_L. But as I only need the deviation of the (log) profit shocks from their plant-specific means in reduced regression (9), the parameter α_L becomes unimportant: $\log(A_{it}) = \log\left(\frac{w_{it} L_{it}^*}{\theta K_{it}^\theta}\right) + \log\left(\frac{1-\alpha_L}{\alpha_L}\right)$, so when subtracting the plant-specific means, the time-invariant term disappears. Therefore it is enough to calculate $A_{it} = \frac{w_{it} L_{it}^*}{\theta K_{it}^\theta}$, for which we have data. I will call the profitability shock calculated this way as type 2 shock.

To numerically calculate the identified profitability shocks, one needs to have an estimate for parameter θ. This is estimated from $\Pi_{it}^* = A_{it} K_{it}^\theta$ (so θ is the "curvature of profit function"). The estimation would be straightforward if all observed profits were strictly positive, as in this case one could take logs and estimate θ from a linear model. But since there are many observations with negative profits, I had to use alternative methods:[23]

(1) I assumed an additive error term and estimated θ with non-linear least squares from the equation $\Pi_{it}^* = A_i K_{it}^\theta + \varepsilon_{it}$ (using fixed effects). To avoid the large impact of larger firms on the estimated θ, I weighted the observations according to their size (measured as sales revenue), so effectively I estimated the equation $\Pi_{it}^* / R_{it} = A_i K_{it}^\theta / R_{it} + \varepsilon_{it} / R_{it}$ (where R_{it} is sales revenues).

(2) I shifted each Π_{it}^* / R_{it} by a constant C to be able to take the log of most observations, and estimated $\ln\left(\Pi_{it}^* / R_{it} + C\right) + \ln\left(R_{it}\right) = \ln\left(A_i\right) + \theta \ln\left(K_{it}\right) + \varepsilon_{it}$ by OLS.

(3) To account for the potential endogeneity of K_{it}, I estimated the same equation $\ln\left(\Pi_{it}^* / R_{it} + C\right) + \ln\left(R_{it}\right) = \ln\left(A_i\right) + \theta \ln\left(K_{it}\right) + \varepsilon_{it}$ with IV (with lagged capital as instrument).

(4) I estimated $\ln\left(\Pi_{it}^* / R_{it} + C\right) + \ln\left(R_{it}\right) = \ln\left(A_i\right) + \theta \ln\left(K_{it}\right) + \varepsilon_{it}$ by OLS on the same sub-sample as in case of IV estimation (we call this method as "sample corrected OLS").

Figure 1 illustrates the estimated θ-s for different outlier-thresholds. (I filtered out outliers according to the left-hand-side variable, Π_{it}^* / R_{it}.) It is obvious from the graph that the NLLS-method is very sensitive to the exact way of outlier exclusion, while the log-model-based estimates do not have similar sensitivity (despite the estimates being different by definition because of the different shift parameter *C*). It is also apparent that IV-estimates are always higher than OLS-estimates, which indicates that capital is endogenous.[24] Also, there is a systematic difference between the original and the sample-corrected OLS-estimates, which is probably because the excluded part of the sample (mainly the 1993-observations that are

[23] Dropping all observations with negative profits is of course a bad solution, as in this case I would probably lose those firms that were hit by negative profitability shocks (or, being more precise: firms hit by negative profitability shocks would be lost with higher probability), leading to selection bias.

[24] The Hausman-test of endogeneity was significant at the 1% level in case of all specifications. This finding is reasonable: capital itself also depends positively on the profit.

used only as instruments for IV-estimation) behaves differently from the remaining part of the sample.

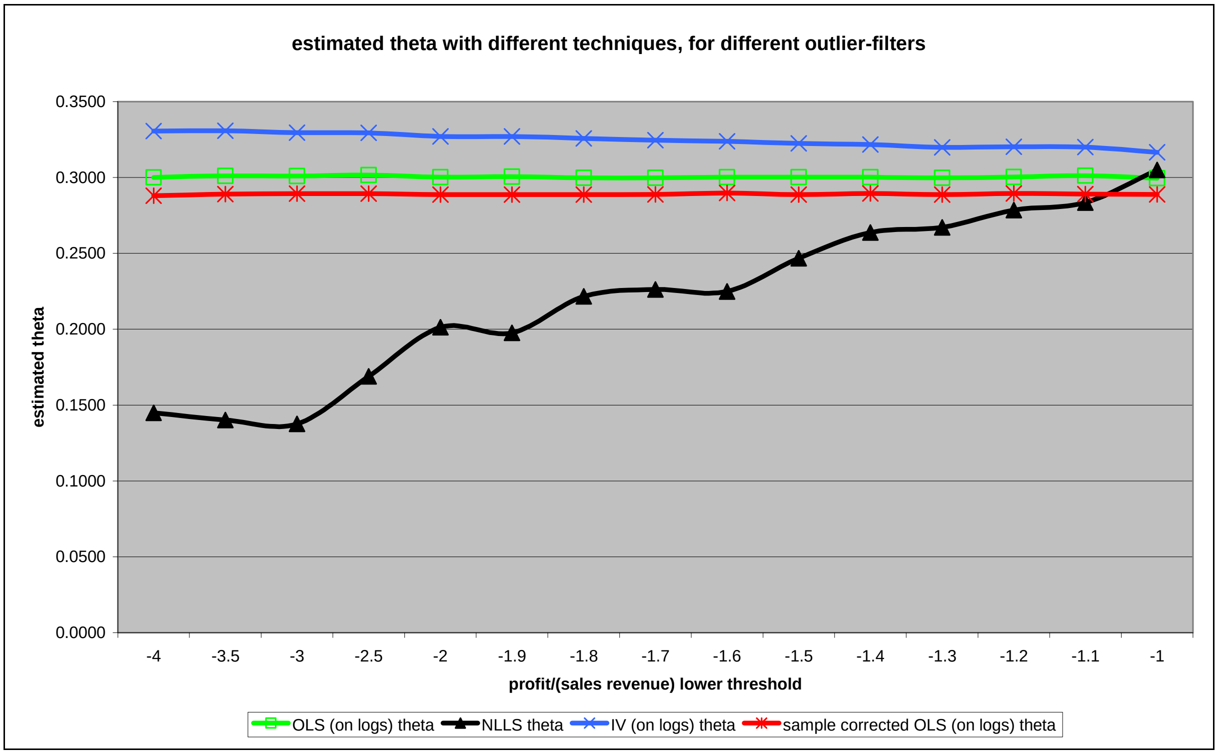

Figure 1. Estimates of parameter θ with different methods, as a function of different outlier filtering.

In what follows, I accept the IV-based estimate of parameter θ. It is apparent from *Figure 1* that the parameter estimates are quite robust for different shift parameters C (they fluctuate between 0.3372 and 0.3301), so I accepted the value that is estimated for the largest possible sub-sample (the one that excludes the lowest number of outliers): $\hat{\theta} = 0.3372$.

To further evaluate the estimated θ,[25] it is interesting to compare it to estimates on other (international) data sets. To my knowledge, there are three comparable estimates in the literature:

(1) On a balanced panel of US manufacturing firms, *Cooper-Haltiwanger (2005)* estimated $\theta = 0.5$.

(2) For an unbalanced panel of US manufacturing firms, *Reiff (2006)* found $\theta = 0.6911$. A balanced sub-sample of this data set gave $\theta = 0.46$ for a similar time period as investigated by Cooper-Haltiwanger.

(3) *Bayraktar et al. (2005)* estimated $\theta = 0.34$ for an unbalanced panel of German manufacturing firms.

Therefore my estimate of parameter θ seems to be much below comparable estimates for US manufacturing firms, but is in line with the findings for Germany. It seems that profits

[25] Since θ is a key parameter to identify profitability shocks, it is important to have a reliable estimate of it. Although shocks identified with different θ-s are strongly correlated, θ is important as it influences the variability of the profitability shock, and also the structural cost parameters themselves.

are much more responsive to capital in the US. (The investigation of the reasons of this phenomenon is beyond the scope of this paper.)

To further evaluate the reliability of the estimated θ, one can investigate the parameter estimates by industries; *Appendix B* contains this exercise. The results show that estimated parameters are higher (and thus profits are more sensitive to capital stock) for those industries which we might think to be relatively more capital intensive *a priori*, and also that the estimated parameters are relatively stable over time. These all indicate the reliability of the overall parameter estimate, so I accept the estimate of $\hat{\theta} = 0.3372$, and identify the profitability shocks accordingly.

As profit, capital and wage bill variables are all available in the data set, I can now calculate both type-1 $\left(A_{it} = \frac{\Pi^*_{it}}{K^{\theta}_{it}} \right)$ and type-2 $\left(A_{it} = \frac{w_{it} L^*_{it}}{\theta K^{\theta}_{it}} \right)$ shocks. Some descriptive statistics about type-2 shocks are reported in *Table 1*.[26] For comparison purposes, similar measures for the US – calculated by *Reiff (2006)* – are also reported. The results show that profitability shocks seem to be more volatile but less persistent in Hungary than in the US.

	Hungary	US (*Reiff 2006*)
Aggregate shock standard deviation	0.1092	0.0822
Aggregate shock autocorrelation	0.6882	0.9325
Idiosyncratic shock standard deviation	0.3155	0.2891
Idiosyncratic shock autocorrelation	0.4033	0.6410

Table 1. Properties of identified type-2 profitability shocks.

To mimic the rich correlation structure[27] of the identified profitability shocks, I decomposed them into aggregate and idiosyncratic shocks. Aggregate shock is defined as the average profitability shock in year *t*: $A_t = \frac{\sum_{i=1}^{N_t} A_{it}}{N_t}$ (here N_t is the number of observations in year *t*), while idiosyncratic shock is simply $\varepsilon_{it} = \frac{A_{it}}{A_t}$.

5.2. Measurement of new investment rates

I measured new investment rates (as opposed to observed gross investment rates) with three alternative ways. Since exact measurement is impossible, all of these are only approximations that are based on (reasonable) assumptions.

In the first method, I use an average depreciation rate (δ) to calculate new (as opposed to gross) investment rate:

[26] As type-1 shock is much more noisy, I work only with type-2 shocks in the rest of the paper.
[27] Shocks are correlated both over time and among firms.

- If the observed gross investment rate is bigger than δ, then I assume that firms engage in cheap replacement investment activity to reduce the need of costly new investment. So in this case there is δ replacement investment (replacing and/or renovating depreciated capital), and thus the new investment rate equals the gross investment rate less δ.
- Alternatively, if the observed gross investment rate is positive, but smaller than δ, then firms could make all their investment activities as replacement investment, which was in fact in their best interest, since this was cost-free. So in this case all investment is replacement investment, and new investment is 0.
- Finally, if the observed gross investment rate is negative, then I assume that there was no replacement investment. This is so because if firms did have some replacement investment, then their need of costly disinvestment (and also their costs) would have increased.

In the second measurement method I assume that firms always make replacement investment that is equal to their observed depreciation, irrespectively of whether their current situation is improving or deteriorating. So in this case new investment is calculated simply by taking the difference between gross investment and depreciation.

Finally, *the third measurement method* is a mixture of the previous two because it makes distinction between replacement investment activity in expansionary and contractionary periods,[28] but it does so on the basis of observed depreciation (as opposed to an average depreciation rate δ in method 1):

- If $INVEST_t > DEP_t$, then capital expenditures exceeded depreciation, so net capital stock increased. I assume that in this "expansionary" case firms undertake as much replacement investment as possible (as this is relatively cheap), and only the increase in the value of net capital stock is the result of the costly new investment activity. So in this case, $NEWINVRATE_t = \dfrac{INVEST_t - DEP_t}{CAPITAL_{t-1}}$.
- If $DEP_t \geq INVEST_t \geq 0$, then the firm's capital expenditures were positive, but since they did not entirely cover depreciation, the firm's former capital stock depreciated to some extent. I assume in this case that all capital expenditures were maintenance-type replacement expenditures, and therefore $NEWINVRATE_t = 0$.
- If $0 > INVEST_t$, then the firm is obviously shrinking. It seems to be logical to assume in this case that no replacement investment was undertaken, as this could have been compensated for only by costly capital sales. In this case $NEWINVRATE_t = INVRATE_t = \dfrac{INVEST_t}{CAPITAL_{t-1}}$.

Figures 2-4 illustrate the resulting new investment rate distributions, when new investment rates are defined according to the different measurement methods. In the rest of the paper I will use the third new investment rate definition as a benchmark, since I think that the first method is only an approximation of method 3, and the second method leads to implausibly high negative investment rate proportions. However, to analyze robustness, in

[28] That is, when firms expend, they make as much replacement investment as possible, while when contracting, they let their capital depreciating.

some cases I will also report the results that are obtained when using the alternative definitions.

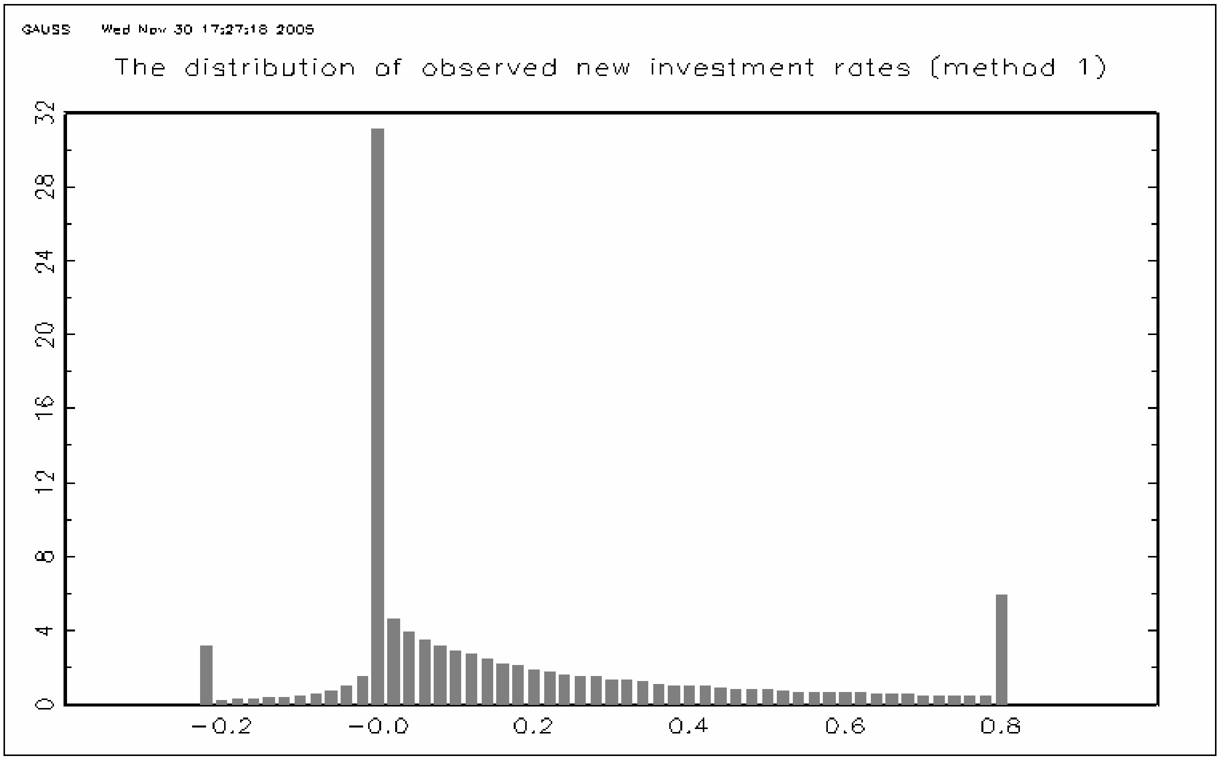

Figure 2. New investment rate distribution, method 1.

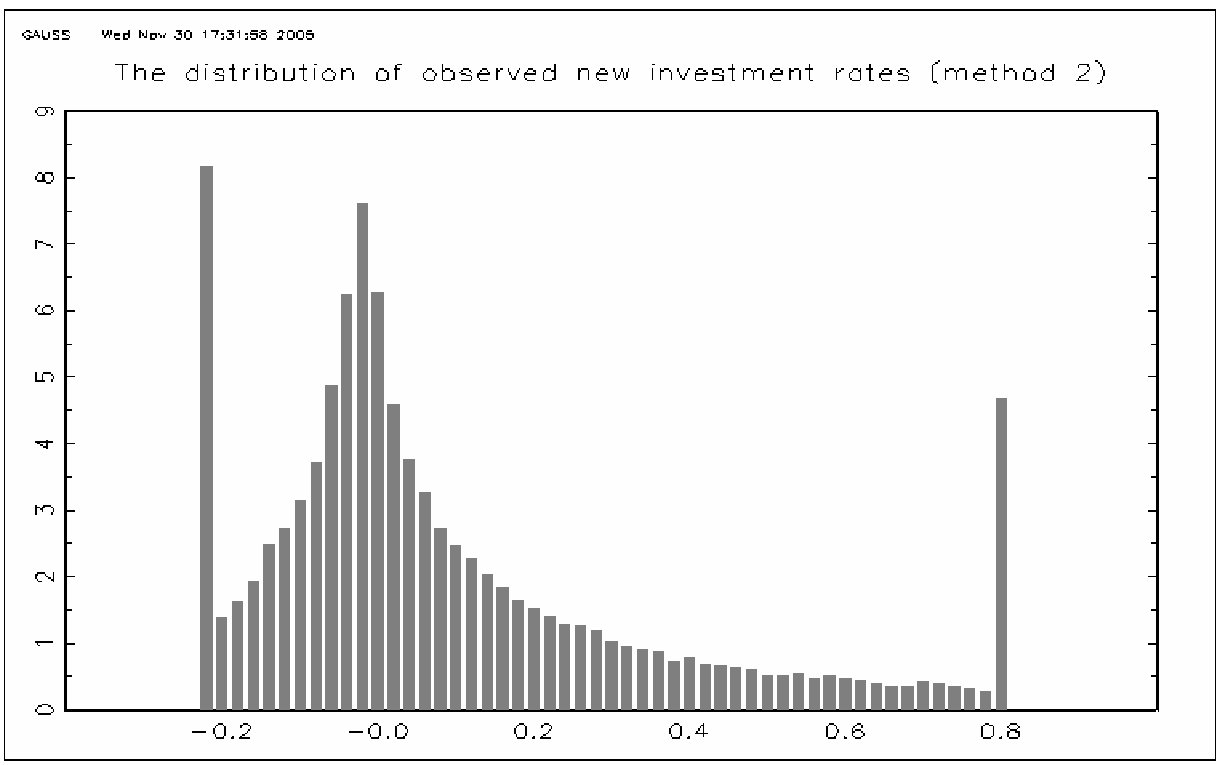

Figure 3. New investment rate distribution, method 2.

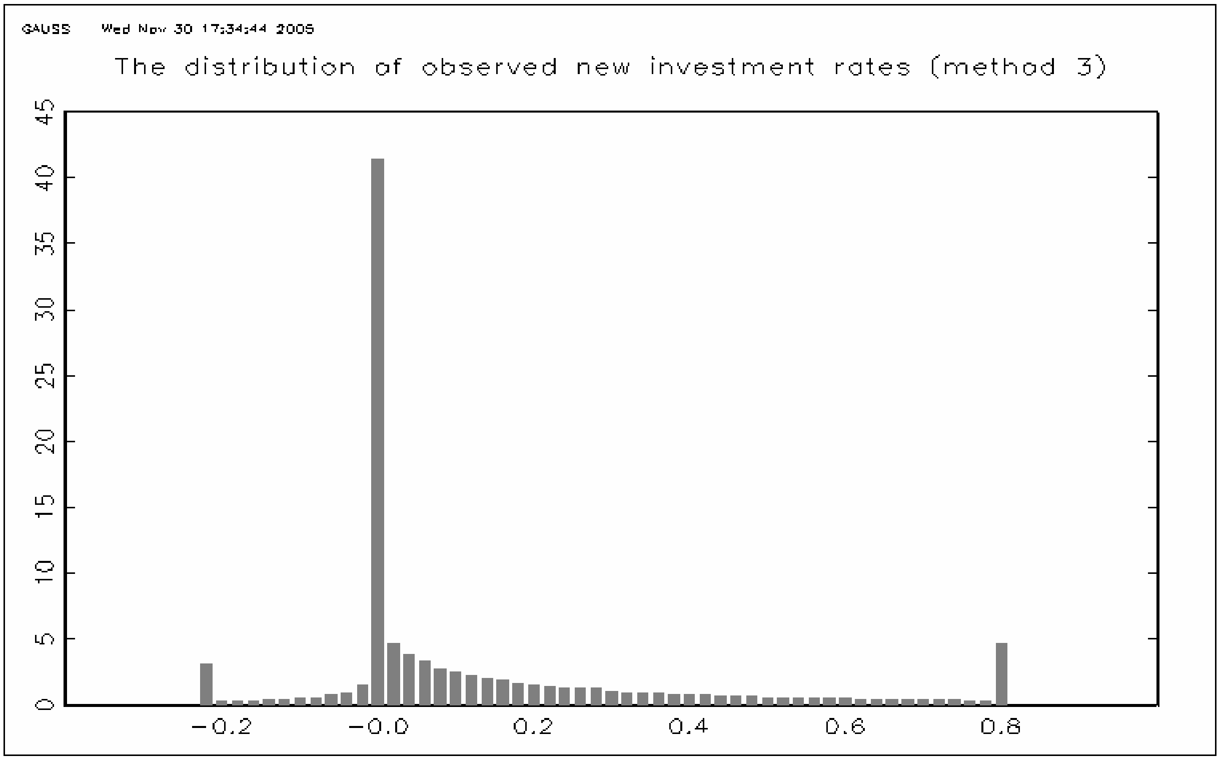

Figure 4. New investment rate distribution, method 3.

Table 2 contains the descriptive statistics of the measured new investment rate distribution (method 3).

	Hungary	US (*Reiff 2006*)
Proportion of negative new investments	10.50%	2.45%
Proportion of inaction	49.64%	42.35%
Proportion of spikes (>20%)	27.73%	19.89%
Mean	13.39%	11.84%
Standard deviation	28.00%	15.10%
Skewness	1.4984	1.2182

Table 2. Descriptive statistics of the new investment rate distribution (method 3).

5.3. Estimation of the reduced-form shock-investment relationship

With the identified profitability shocks and investment rates, I can now estimate the reduced-form shock-investment relationship, which is the key to identify the structural cost parameters. According to equation (9), the specification that we estimate is a quadratic one between investment and profitability shocks, with lagged shocks also included. The quadratic term is included to capture fixed-cost- and irreversibility-induced non-linearity, while the lagged variable captures lumpiness (also due to either irreversibility or fixed costs).

Table 3 contains the estimated parameters of this regression for alternative measurements of new investment rate. It is apparent from the table that estimated parameters are robust to the way of measurement of the new investment rate. The only exception is $\hat{\phi}_2$, which is much lower in case of method 1 than for alternative methods. This probably means that the assumption of an average depreciation rate (for calculating method 1 new investment rate) is not appropriate.

Table 3 also contains the estimated parameters of the same reduced-form regression for US data, as reported by *Reiff (2006)*. The structure of the estimated parameters is surprisingly similar.

I will use these estimated parameters (together with observed inaction rate and observed investment rate distribution skewness) to identify the structural cost parameters of the theoretical model.

	Method 1	Method 2	Method 3	US (*Reiff, 2006*)
Estimated ϕ_1	0.1343 (0.0099)	0.1466 (0.0106)	0.1354 (0.0097)	0.1150 (0.0085)
Estimated ϕ_2	0.0297 (0.0216)	0.0784 (0.0234)	0.0723 (0.0214)	0.0822 (0.0147)
Estimated ϕ_3	-0.0369 (0.0080)	-0.0368 (0.0084)	-0.0343 (0.0076)	-0.0251 (0.0081)
Number of firms	12,918	12,984	12,984	1,554
Number of observations[29]	50,470	51,485	51,485	23,413

Table 3. Estimated reduced regression parameters (with standard errors) for alternative new investment rate measurement methods.

6. Estimation of structural cost parameters

I identify the structural cost parameters by matching the parameters of the theoretical shock-investment relationship, the theoretical inaction rate and the theoretical investment rate distribution skewness to empirically observed values reported in the previous section. The parameters of the theoretical shock-investment relationship, the theoretical inaction rate and the theoretical investment rate distribution skewness are obtained by simulating the theoretical model for arbitrary cost parameters (F, γ, p). The simulation involves the following steps:

Step 1. Determine the value- and policy functions of the theoretical model for arbitrary cost parameters (F, γ, p). I solve the model by value function iteration on fine grids with respect to the state variables (A, K), and assuming that shocks have the same distribution

[29] The number of observations is larger when we measure investment rate according to methods 2-3, based on observed depreciation (as opposed to an average depreciation rate δ). The reason of this is that in case of method 1, the number of investment outliers (defined as investment rates above 125%) is much larger.

as observed from data.[30] I also assume that $\beta = 0.95$ and $\delta = 0.07$, where the latter is an average depreciation rate reported by *Kátay-Wolf (2004)*.[31]

Step 2. With the policy functions obtained in *Step 1*, simulate artificial data sets of the same size as the original data set. As a starting point, I simulate profitability shocks, using again the observed distribution of shocks. Then I use the policy function obtained in *Step 1* to simulate the capital paths of the hypothetical firms in the artificial data set, and calculate the corresponding investment rates.

Step 3. Estimate the reduced-form shock-investment relationship in the simulated data set, and also the inaction rate and the investment rate distribution skewness.

Step 4. Choose a cost parameter vector (F, γ, p) for which the distance between simulated and observed reduced-regression parameters, inaction rate and investment rate distribution skewness is the smallest.

Table 4 illustrates that for cost parameters $F = 0.0001$, $\gamma = 0.22$, $p = 0.991$, the simulated reduced-regression parameters, inaction rate and investment rate distribution skewness are quite close to their observed values. In fact I found that the distance between the simulated and observed values (weighted by the inverse of the standard deviation of each estimate) is the smallest for this vector of cost parameters, which means that this is my estimate for the structural cost parameters.

	Observed	Simulated for $F = 0.0001$, $\gamma = 0.22$, $p = 0.991$
Reduced regression ϕ_1	0.1354	0.1207
Reduced regression ϕ_2	0.0723	0.0540
Reduced regression ϕ_3	-0.0324	-0.0669
Non-positive investments	60.15%	60.02%
Investment rate skewness	1.4984	1.4872

Table 4. Observed and simulated reduced regression parameters, non-positive investment rates and investment rate distribution skewness for “best” cost parameters.

Table 5 reports the estimated structural cost parameters and their standard errors for various cases. If I specify the cost function with only convex costs (*column 4*), the estimated convex cost is relatively high ($\hat{\gamma} = 0.7605$), but the distance of the simulated statistics from their observed counterparts is quite high (150.14).

Allowing for the existence of fixed costs (*column 3*), this distance decreases substantially (to 50.87), indicating that the match improved. The estimated convex cost parameter also declines (to $\hat{\gamma} = 0.479$), which may interpreted as increasing fixed costs compensate for decreasing convex costs.

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[30] Here I used the rich correlation structure of the shocks, by assuming that overall shocks are the sum of aggregate and idiosyncratic shocks, with standard deviations and autocorrelations reported earlier.

[31] In principle, these are also structural parameters of the model, so in fact one should estimate them jointly with the other structural parameters. But since the focus of this paper is on estimating the structural *cost parameters*, I decreased the dimension of the parameter vector to be estimated to 3. This leads to a considerable reduction computation time.

If I further generalize the cost structure by allowing for irreversibility costs (*column 2*), then the distance decreases further (by approximately 16%). In this case increasing irreversibility costs compensate for decreasing fixed and convex costs, while improving the overall match.

	Fixed, convex and irreversibility costs	*Fixed and convex costs*	*Only convex costs*
F (fixed costs)	0.000100 (0.000018)	0.000119 (0.000007)	(0)
γ (convex costs)	0.220 (0.033322)	0.479 (0.039347)	0.7605 (0.001969)
p (irreversibility)	0.991 (0.002376)	(1)	(1)
DISTANCE	**42.61**	**50.87**	**150.14**

Table 5. Estimated structural cost parameters and standard errors.

The estimated fixed cost parameter, though being significant, is numerically small, even if one compares it to similar estimates of *Cooper-Haltiwanger (2005)* $(F = 0.039)$ and *Bayrakhtar et al. (2005)* $(F = 0.031)$. This estimate means that the fixed cost is 1% of the purchase price of a 1% investment rate.[32]

The estimated convex cost parameter is in line with other results in the literature, with *Cooper-Haltiwanger (2005)* reporting an estimate of 0.049, while *Bayrakhtar et al. (2005)* estimate $\gamma = 0.532$.

The estimated irreversibility is significant, but indicates small degree of irreversibility, a similar phenomenon that was also observed by the other two comparable studies (*Cooper-Haltiwanger, 2005* had an estimate of 0.975, while the initial version of *Bayrakhtar et al., 2005* reported $p = 0.902$). It is common in these type of estimates that they are much lower than direct irreversibility estimates (*Ramey-Shapiro, 2001* estimated an average discount of 72% on capital sales, while *Reiff, 2004* had a discount rate of approximately 50%).

In order to evaluate the relative significance of the different adjustment costs, I investigated the investment costs of certain investment episodes. For example, if a firm has a negative investment of -5%, then it has to pay a fixed cost of 0.0001, a convex cost of (0.22/2)*(-0.05)*(-0.05)=0.000275, and an irreversibility cost of 0.009*0.05=0.00045. So the total adjustment cost is 0.000825, or 1.65% of the total frictionless sales price (which is 1*0.05=0.05), out of which 12.1% is fixed cost, 33.3% is convex cost, and 54.6% is irreversibility cost.

On the other hand, if firms engage in an average investment project observed from data (when investment rate is 13.39%), then fixed costs are 0.0001, and the size of convex costs is (0.22/2)*0.1339*0.1339=0.001972, so of all adjustment costs, 95.2% is convex costs and 4.8% is fixed costs.[33]

[32] As I normalize the model to the purchase price of capital, an investment rate of 1% costs 1*0.01=0.01.
[33] For larger investments, convex costs obviously “take over”. Also, for positive investments there are no direct irreversibility costs.

7. Aggregate implications

In this section I analyze how monetary policy affects aggregate investment. To do so, I assume that monetary policy enters the model through the aggregate profitability shock. Monetary policy decisions translate to a profitability shock, because changing interest rates and/or exchange rates both affect the profitability of firms for obvious reasons. I also assume that monetary policy is an *aggregate* profitability shock because it has more or less similar effects on different firms.[34]

To fully understand the effect of monetary policy on aggregate investment, theoretically we should disentangle two effects: (1) to what extent monetary policy affects aggregate profitability;[35] and (2) how changes in aggregate profitability affect aggregate investment. Naturally, in the current modeling framework one can address the second question, and can not say much about the first one. Therefore in the following I investigate the second question, and leave the first one to further research.[36]

I analyze the aggregate implications of the firm-level results along two dimensions. The first comparison is based on the differences between firm-level and aggregate behavior. This approach is similar to that of *Caballero (1992)*, where the main focus is on the differences between micro- and macro-level phenomena.[37] The second dimension of the comparison is based on the differences between the adjustment patterns for different cost structures: when there are only convex costs (so the adjustment is smooth), and when all kinds of adjustment costs are included into the analysis. So this approach tries to answer the question whether the existence of non-convex cost components has any important effects on aggregate variables. This analysis is similar to *Veracierto (2002)*, who compares the behavior of aggregate variables in two extreme cases: when there is complete irreversibility, and when there is no irreversibility.[38]

7.1. Comparison of firm-level and aggregate shock-investment relationship

[34] One may argue that this is not necessarily true: firms with higher external financing needs may find that a certain increase in interest rates reduced their profitability more dramatically than others. Also, firms more exposed to foreign markets may feel exchange rate changes more influential than others. Still, I think that the assumption that monetary policy acts like an aggregate profitability shock is a good approximation.

[35] Optimally, the answer to this question should look like these statements: a 1 percentage point increase of the interest rate decreases aggregate profitability by ??? percents. Or: a 1-percent devaluation of the exchange rate changes aggregate profitability by ??? percents.

[36] *Jakab-Vonnák-Várpalotai (2006)* investigate the effect of a monetary policy shock to aggregate investment in three alternative models for the Hungarian economy, and find that a 1% monetary policy shock (as they define) induces a cumulative change of approximately 0.2% in aggregate investment.

[37] The main result of that paper is that even if there is asymmetric adjustment at the micro-level, under general conditions (if shocks that hit the firms are not perfectly harmonized) this asymmetry vanishes at the macro-level because of aggregation.

[38] The main finding of this paper is that irreversibility is unimportant for the behavior of aggregate variables: the evolution of aggregate variables is the same, irrespectively from the degree of irreversibility. This result may seem a bit surprising, but it is a direct consequence of the relatively low variance of the production shock that hits the plants. For larger shocks, the irreversibility constraint would become effective at least in some cases, and also the aggregate behavior of the key variables would be different when there is irreversibility.

To compare firm-level and aggregate investment dynamics, I estimated the reduced-form regressions ($\tilde{i}_{it} = \phi_0 + \phi_1 \tilde{a}_{it} + \phi_2 \tilde{a}_{it}^2 + \phi_3 \tilde{a}_{i,t-1} + \mu_t + u_{it}$) for both firm-level and aggregate data, simulated for various cost structures.[39] The estimated parameters for the different scenarios are in *Table 6*.

		Only convex costs (F=0, γ=0.7605, p=1)	*Convex and fixed costs* (F=0.000119, γ=0.479, p=1)	*All types of costs* (F=0.0001, γ=0.22, p=0.991)
Aggregate level	ϕ_1	0.0655 (0.0030)	0.0877 (0.0042)	0.1281 (0.0067)
	ϕ_2	0.5069 (0.3817)	0.8029 (0.5353)	1.3125 (0.8572)
	ϕ_3	-0.0195 (0.0030)	-0.0307 (0.0042)	-0.0554 (0.0067)
	N	28	28	28
Firm-level	ϕ_1	0.0613 (0.00010)	0.0822 (0.00013)	0.1207 (0.00017)
	ϕ_2	0.0224 (0.00023)	0.0357 (0.00030)	0.0540 (0.00045)
	ϕ_3	-0.0265 (0.00010)	-0.0389 (0.00013)	-0.0669 (0.00013)
	N	28*7000	28*7000	28*7000

Table 6. Aggregate and firm-level reduced regression parameters under different cost structures (estimated from simulated data sets). Standard errors are in parenthesis.

The results show that the parameters of the linear terms (ϕ_1 and ϕ_3) have similar patterns: they increase (in absolute terms) as we allow for fixed and irreversibility costs. Also, the parameter estimates are numerically close to each other in these cases. The major difference arises in case of the non-linear term (ϕ_2): despite being significant at the firm-level, it becomes insignificant at the aggregate level. This result is robust across different cost specifications.

7.2. Comparison of convex and non-convex investment cost structures

To analyze the aggregate implications of the non-convex costs of investment, I compare the behavior of aggregate variables after certain aggregate shocks for different cost structures.

The first case under my focus will be the one where fixed and irreversibility costs are excluded from the analysis, and all the adjustment costs are assumed to be convex costs.

[39] Of course, while on the firm-level the reduced regression is estimated on a panel, on the aggregate level this can only be done on a time series (and for much smaller number of observations).

According to *Table 5*, the estimated convex cost parameter is $\gamma = 0.7605$ in this case (with $F = 0$ and $p = 1$ fixed).

The second scenario will be the one when there are convex and fixed costs, but no irreversibility cost. Under these assumptions I estimated the cost components as $\gamma = 0.479$ and $F = 0.000119$ in *Table 5*.[40] Intuitively, the effect of convex costs is partially taken on by the fixed cost component.

The third case is the one when all cost components are allowed. Earlier I estimated the different cost parameters as $\gamma = 0.220$, $F = 0.0001$ and $p = 0.991$. Now the increasing irreversibility costs compensate for decreasing fixed and convex cost components.

To analyze the aggregate effects, I make three experiments for all of these three cost structures. In the first experiment, I simulate initial (aggregate + idiosyncratic) profitability shocks and corresponding capital paths for $N = 7000$ hypothetical firms, assuming that (log) aggregate shocks are 0 during periods 0-100, and equal to the standard deviation of the aggregate shock (0.1092, as measured empirically) from the 101st time period.[41] Idiosyncratic shocks are drawn from the same distribution that I observed empirically. So the assumption is that firms are hit by a permanent profitability shock at the 101st time period. For simplicity, in the following I index this 101st time period as $t = 1$.

Figure 5 illustrates the effect of this permanent profitability shock on the aggregate gross (replacement + new) investment rate.[42] The first thing to observe is that a permanent profitability shock of 10.92% immediately increases the aggregate gross investment rate by only 1.3-2.1%, a relatively moderate rate, and it has a cumulative effect of 4-5% during the next 5-6 periods (years).

It is also interesting to observe that in the presence of non-convex (fixed and irreversibility) costs, the aggregate response is higher. This is because if we have only convex costs, the estimated convex cost parameter is necessarily higher, which “punishes” relatively large investment episodes. On the other hand, in case of all types of costs convex costs are relatively lower and non-convex costs are relatively higher, so large investment episodes are relatively cheaper. So it is intuitive that in case of both convex and non-convex costs, the immediate response to the positive profitability shock is somewhat larger, and the impulse response function becomes zero relatively earlier.

So there is an apparent difference between the firm-level and aggregate effects of non-convex adjustment costs: while *fixed and irreversibility costs make investment lumpy at the firm level, aggregate investment is more flexible if we also have fixed and irreversibility cost components*.

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[40] And also noted that the fit of the model has increased dramatically: the “loss” decreased from 150.14 to 50.87.

[41] Allowing for 100 initial periods ensures that the results are not affected by the initial conditions.

[42] To ease interpretation, the deviation of steady state is depicted on the vertical axis. The steady state gross investment rate is equal to the average depreciation rate, and is therefore non-0.

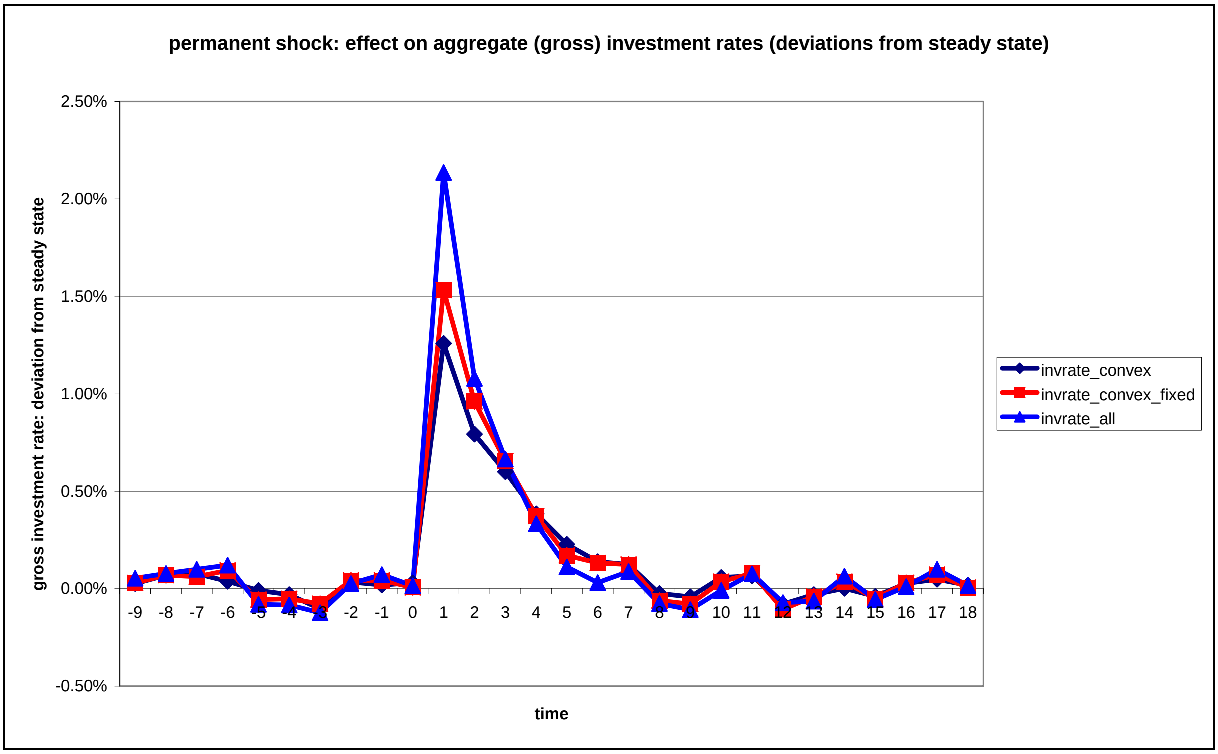

Figure 5. The effect of a permanent profitability shock on aggregate gross investment rate.

Figure 6 depicts the effect of the same permanent profitability shock to the aggregate new investment rate. It is apparent from the figure that there are differences between the various cases in the steady state aggregate new investment rates. Specifically, the steady-state new investment rate[43] is relatively larger when there are both convex and non-convex investment cost components. This is again because relatively lower convex costs and relatively larger non-convex costs make larger new investment episodes relatively cheaper.

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[43] The steady-state gross investment rate (which is the average depreciation rate) is held constant in the three cases.

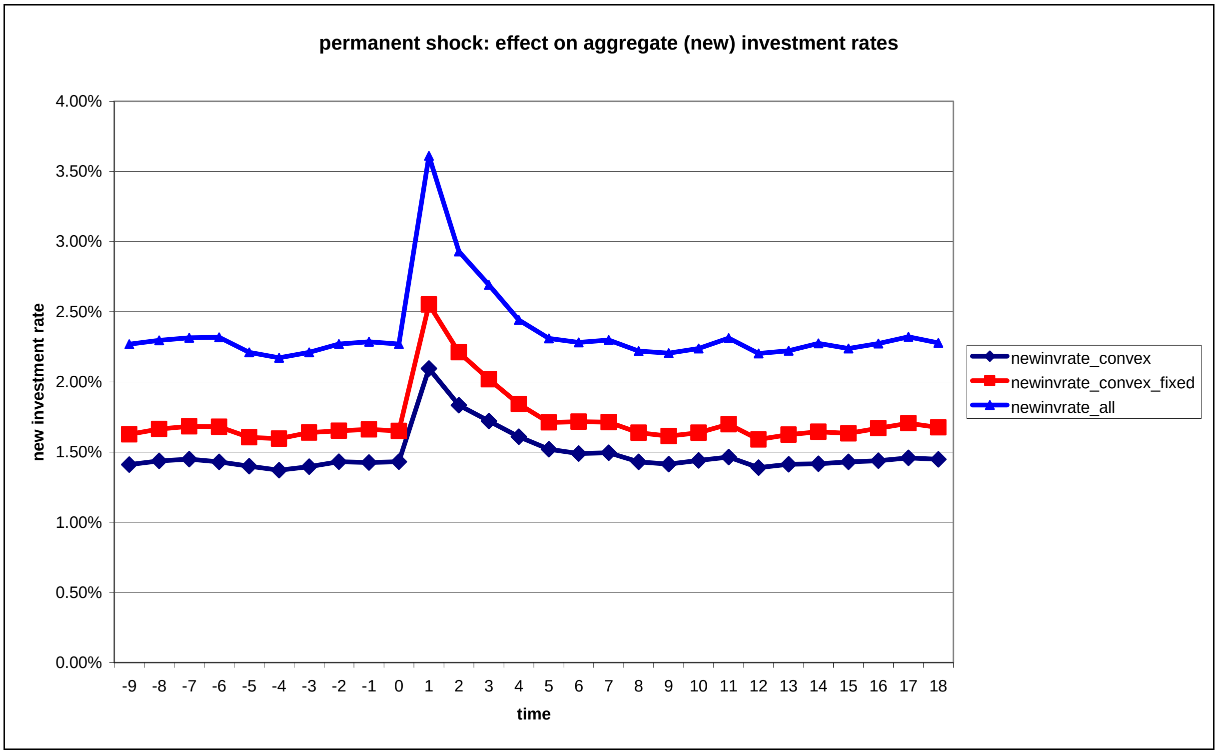

Figure 6. The effect of a permanent profitability shock on aggregate new investment rate.

In the second experiment I investigate the effect of a transitory profitability shock at $t = 1$ (again, to avoid initial value problems I simulate 100 initial periods). Now I assume that the (log) profitability shock is 0 during the initial 100 periods; it is 0.1092 (as measured from data) at $t = 1$, and is again 0 thereafter. *Figures 7-8* depict the effect of this one-standard-deviation transitory shock to the aggregate gross and new investment rates.[44] For the gross investment rates, the same story emerges as in case of permanent shocks: as convex costs punish large investments relatively more, the aggregate response is larger for relatively smaller convex cost components (that is, if we allow for all cost components). As for new investment rates, the steady state new investment rate is again the largest when convex costs are relatively lower; one can observe the largest response in this case.

[44] In case of gross (replacement + new) investment rate, I again depict deviations from steady-state.

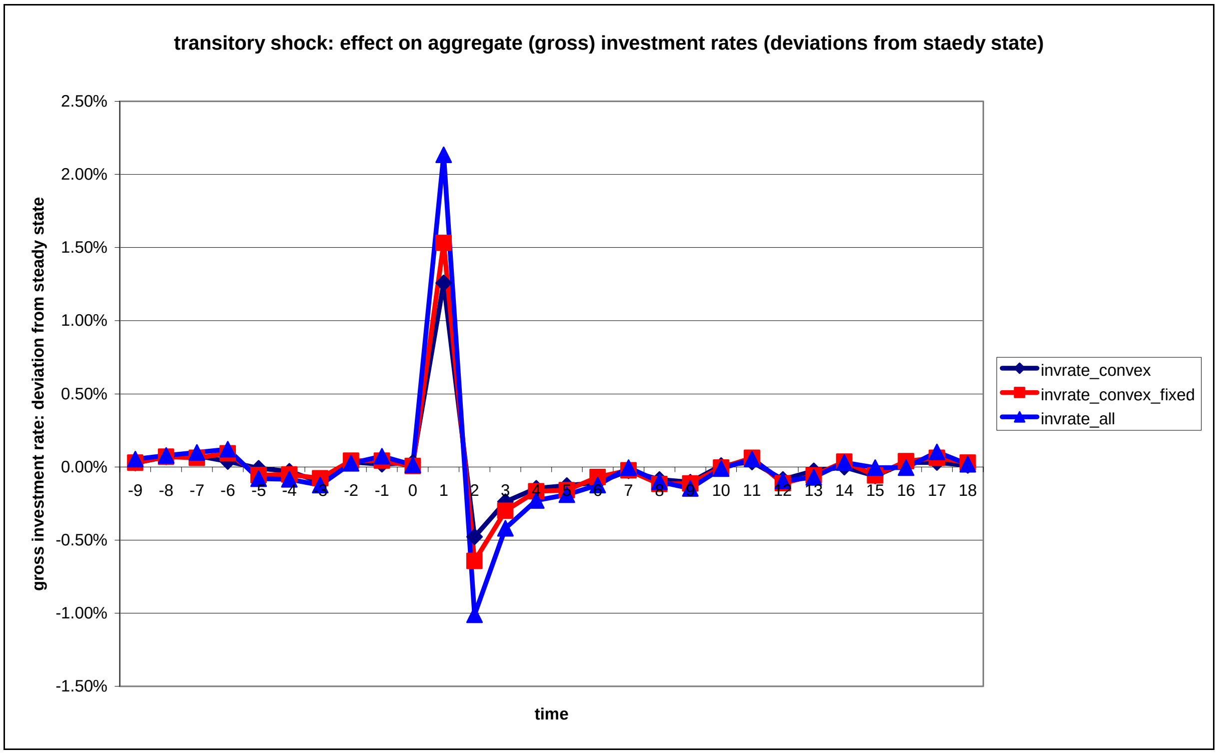

Figure 7. The effect of a transitory profitability shock on aggregate gross investment rate.

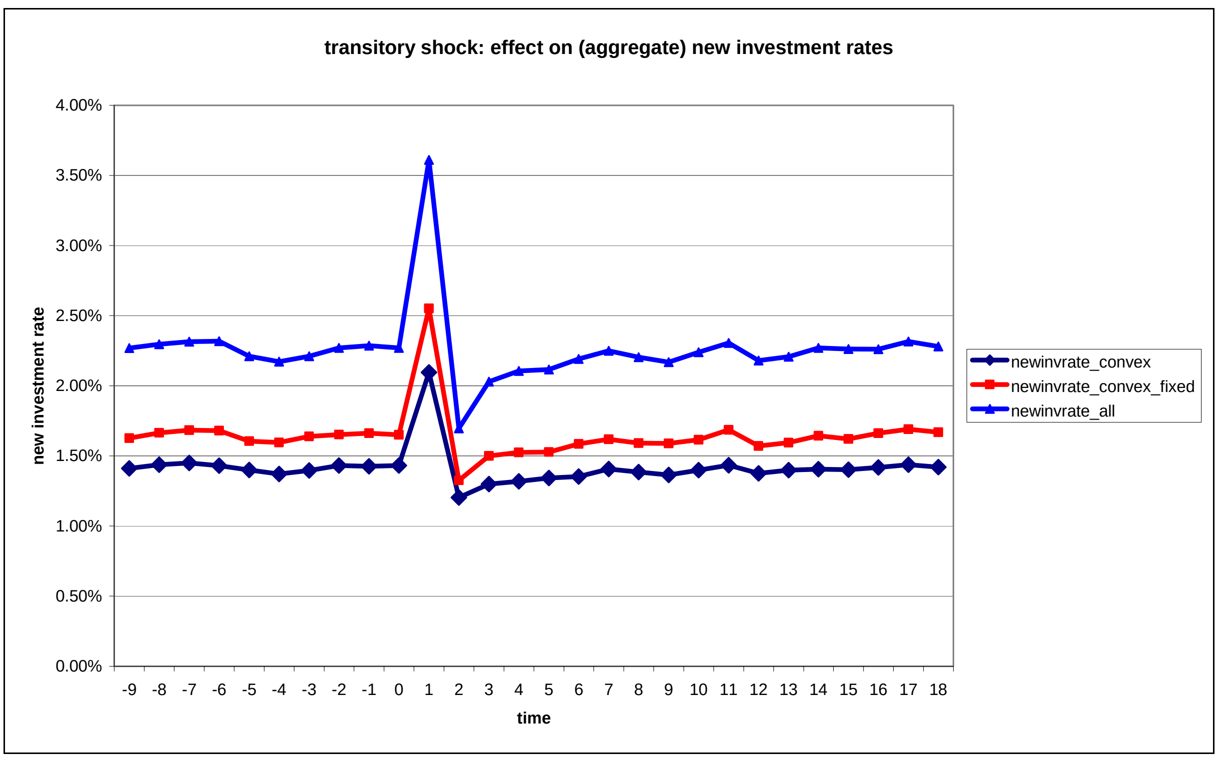

Figure 8. The effect of a transitory profitability shock on aggregate new investment rate.

While these experiments are important to improve our understanding of the effects of the different investment costs on the behavior of various aggregate investment rates, they are not too realistic in the sense that they assume that one can have a perfect control of the aggregate shock hitting the firms. In reality no institution can alone influence the aggregate profitability shock, so one should not assume this. To evaluate the impact of a certain policy (for example, if the central bank improves "aggregate profitability" by making the loans cheaper) it is more appropriate to assume that the profitability shock remains stochastic (in the sense it was stochastic in the previous sections), and the policy-induced permanent shock is in addition to this underlying stochastic profitability shock.

Therefore, as a third experiment, I simulated aggregate investment rates after a permanent profitability shock under these circumstances. The underlying stochastic aggregate profitability shock was as measured empirically,[45] and there is an additional positive aggregate profitability shock of 0.1092 from period 101 ($t = 1$). *Figure 9* depicts the behavior of the aggregate gross investment rate (deviation from steady state) after such a permanent shock. Obviously, the variance of the aggregate gross investment rate over time is much larger in this case than previously, as now it also depends on the evolution of the underlying aggregate shock that cannot be controlled. Otherwise, this figure is quite similar to the previous figures about aggregate gross investment rates: the largest responses occur when convex costs are relatively small (and other types of costs are relatively larger).

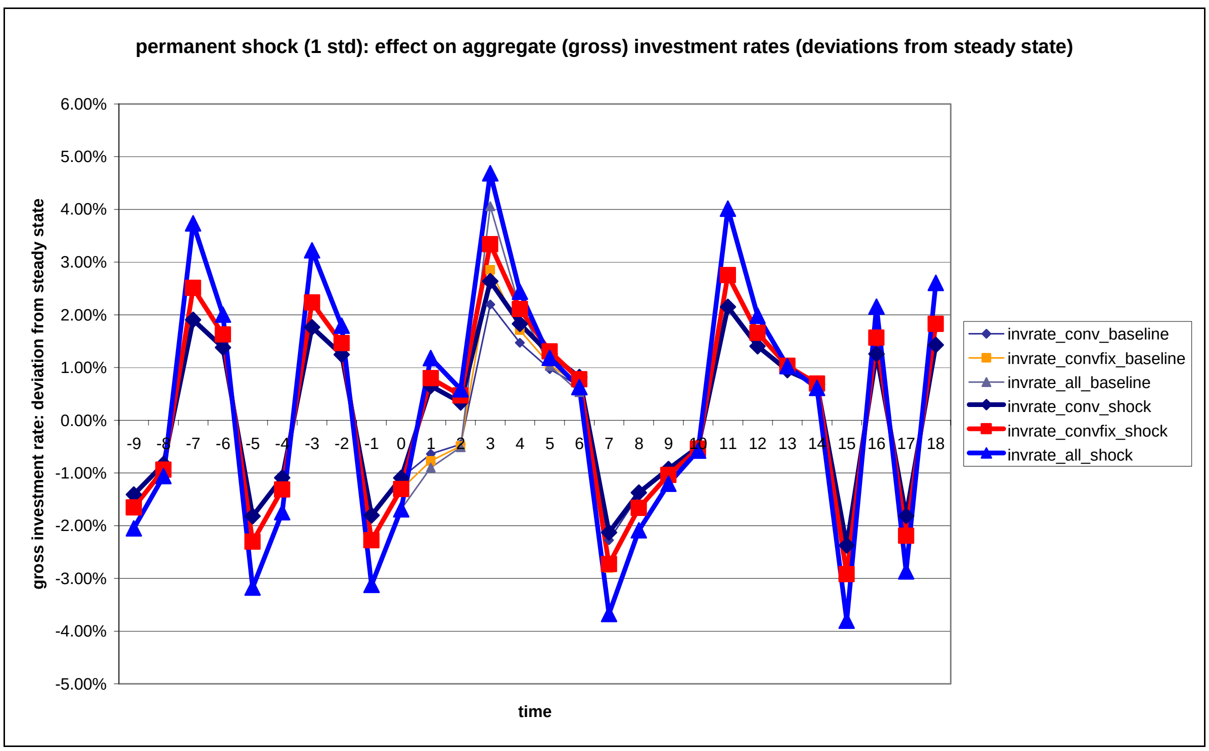

Figure 9. The effect of a permanent profitability shock (in addition to the regular profitability shock) on aggregate gross investment rate (deviation from steady state). For comparison purposes, I depict also what would have happened if there was no extra profitability shock (BASELINE).

Figure 10 illustrates the effect of a similar permanent aggregate profitability shock to the new investment rates. It is apparent from the figure that while the absolute responses are still higher when convex costs are relatively small and fixed and irreversibility costs are

[45] Its standard deviation and autocorrelation is 0.1092 and 0.6882, respectively.

relatively high, because of irreversibility, the aggregate new investment rate is less flexible downward than upward.[46]

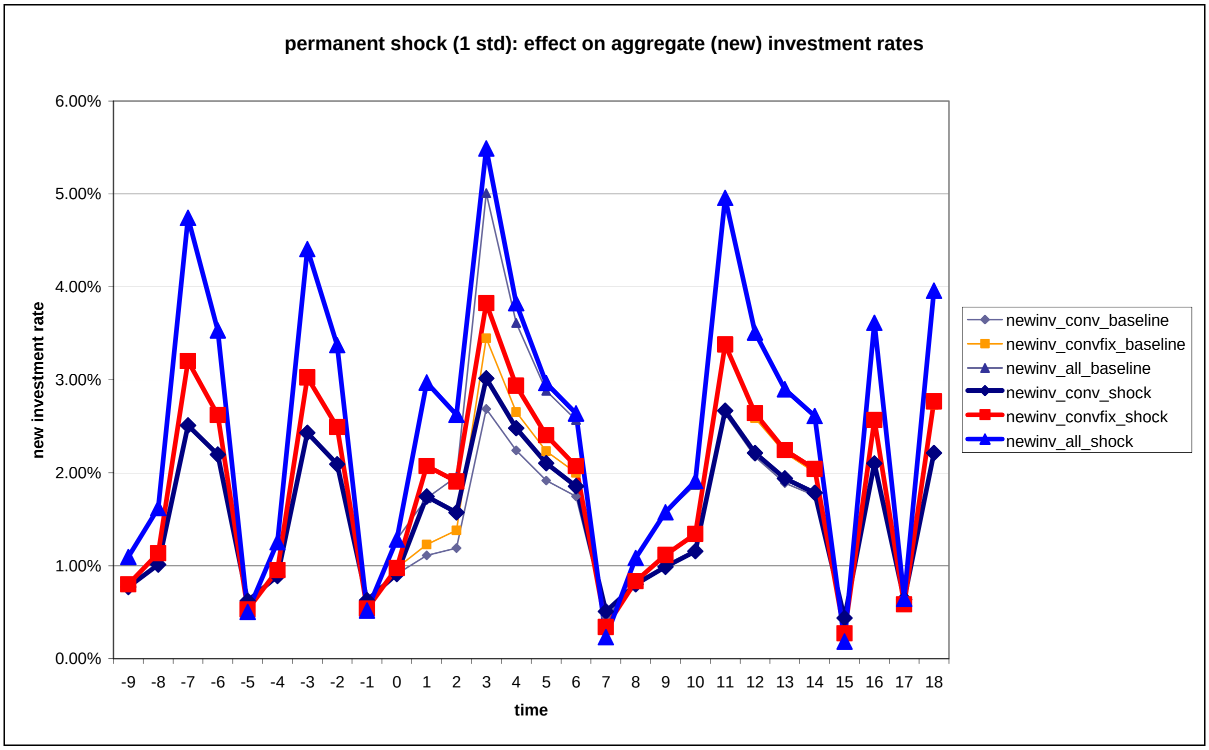

Figure 10. The effect of a permanent profitability shock (in addition to the regular profitability shock) on aggregate new investment rate. For comparison purposes, I depict also what would have happened if there was no extra profitability shock (BASELINE).

As a final experiment, I simulated the effect of the same set of permanent shocks when the permanent profitability shock is credible and foreseen. This means that once a shock (of 1 standard deviation) occurs in period 1, firms know that this shock will be permanent and form their expectations about future profitability condition accordingly.[47]

Figures 11-12 illustrate the case of a credible permanent profitability shock, when perfectly controlled by the authorities (so no aggregate shock that is independent from the authorities occurs); one should then relate these figures to *Figures 5-6*. It is apparent from *Figure 11* that if the positive permanent profitability shock is foreseen, and it enters into firms' expectations, then its effect is much bigger. I reported earlier that if the permanent shock is a surprise shock in each period, then the immediate effect of a 1 standard deviation positive permanent shock is 1.3-2.1%, and the cumulative effect is 4-5% during the following 5-6 periods. Now if the permanent profitability shock is anticipated, then its immediate effect is as high as 7.2-11.5%, while the cumulative effect is 24.1-24.3% during the next 10 periods. So if authorities can make the intended positive profitability shock foreseen and credible, then its effect can be much bigger.

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[46] After clearly worsening aggregate profitability conditions, aggregate new investment rate is reluctant to go into the negative regions.

[47] So far I had an implicit assumption that in case of a permanent shock, it was a "surprise shock" in each time period, in the sense that firms did not alter their expectations according to this permanent shock.

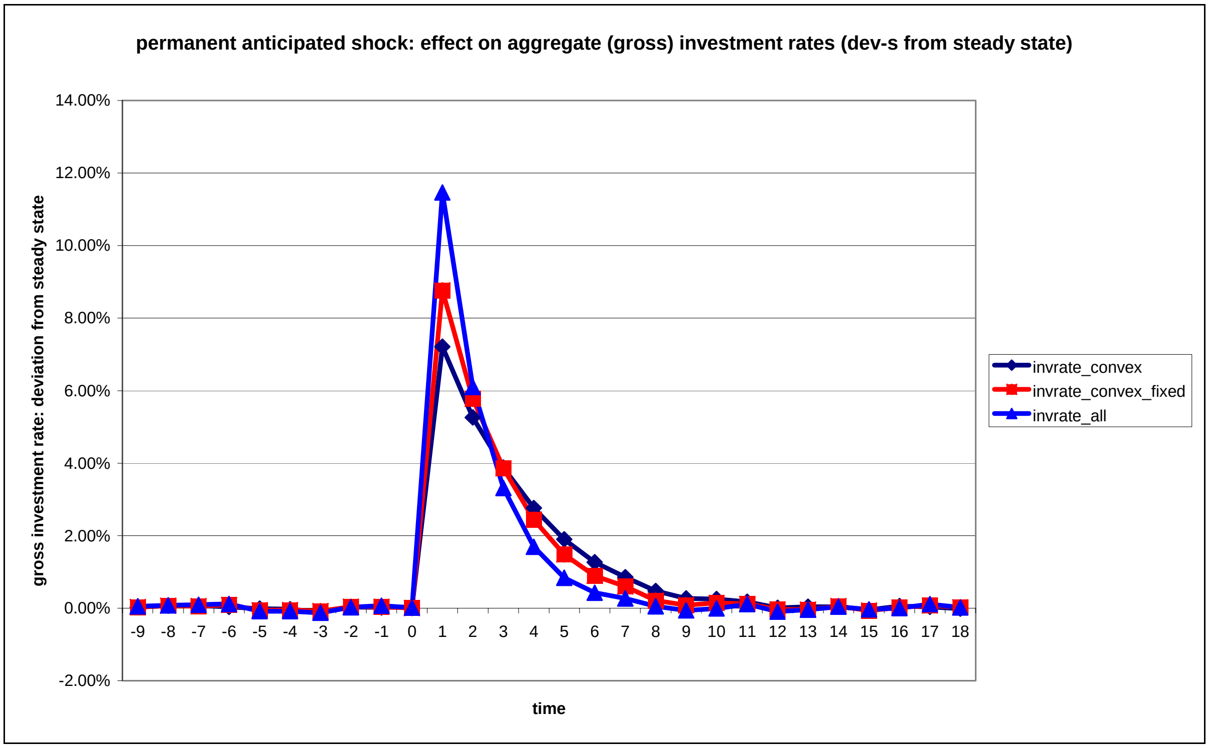

Figure 11. The effect of a permanent anticipated profitability shock on aggregate gross investment rate.

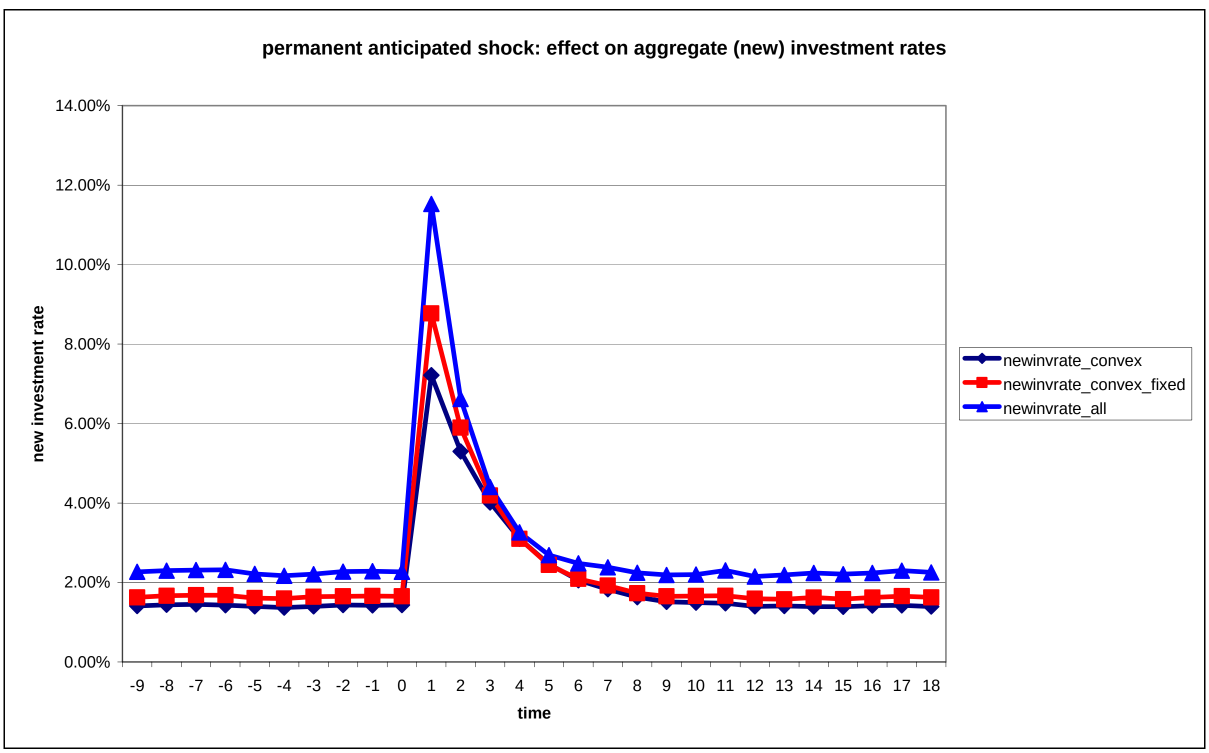

Figure 12. The effect of a permanent anticipated profitability shock on aggregate new investment rate.

Also, it is apparent (perhaps even more than before) from the figures that aggregate investment is the most responsive to profitability shocks if we have all types of investment costs, which is the same result that I reported earlier for unanticipated permanent profitability shocks.

So the earlier finding is robust across different specifications of artificial shocks: the response of aggregate investment under both convex and non-convex investment costs to certain profitability shocks is more flexible than if we only have convex adjustment costs.

To further study the *dynamics* of investment adjustment under different cost structures, it may be useful to track the distribution of firm-level adjustments after a profitability shock. The observed inaction rate can be particularly interesting after such a hypothetical profitability shock. *Figure 13* illustrates the inaction rate (the proportion of firms that stay inactive) after a permanent profitability shock.[48] As we saw on *Figure 5*, adjustment is quicker (that is, aggregate investment rate is higher in the first 3-5 periods after the shock) in this case if we have all types of adjustment costs, as opposed to only convex costs. It is apparent on *Figure 13* that this quicker adjustment takes place mainly on the intensive margin: higher aggregate investment rates occur at similar inaction rates, from which we can infer: (1) if we have all types of adjustment costs, those firms that adjust must make relatively larger adjustments than in case of only convex costs,[49] and (2) those firms that remain inactive when we have only convex costs, also tend to remain inactive if we have all types of adjustment costs. Experimenting with the other two types of aggregate profitability shocks leads to the same conclusion: adjustment takes place at the similar inaction rates under the different cost specifications, so adjustment takes place on the intensive margin also in these cases. These are all further pieces of evidence that non-convex adjustment costs have important effects on aggregate dynamics.

[48] In this case we assume that there are no other sources of aggregate uncertainty: aggregate profitability increases by exactly one standard deviation from $t=1$. So in terms of shock structure, *Figure 11* corresponds to *Figure 5*.

[49] In fact, it is apparent from *Figure 11* that when we have all types of adjustment costs, the larger aggregate adjustment (illustrated on *Figure 5*) takes place at a slightly higher inaction rate.

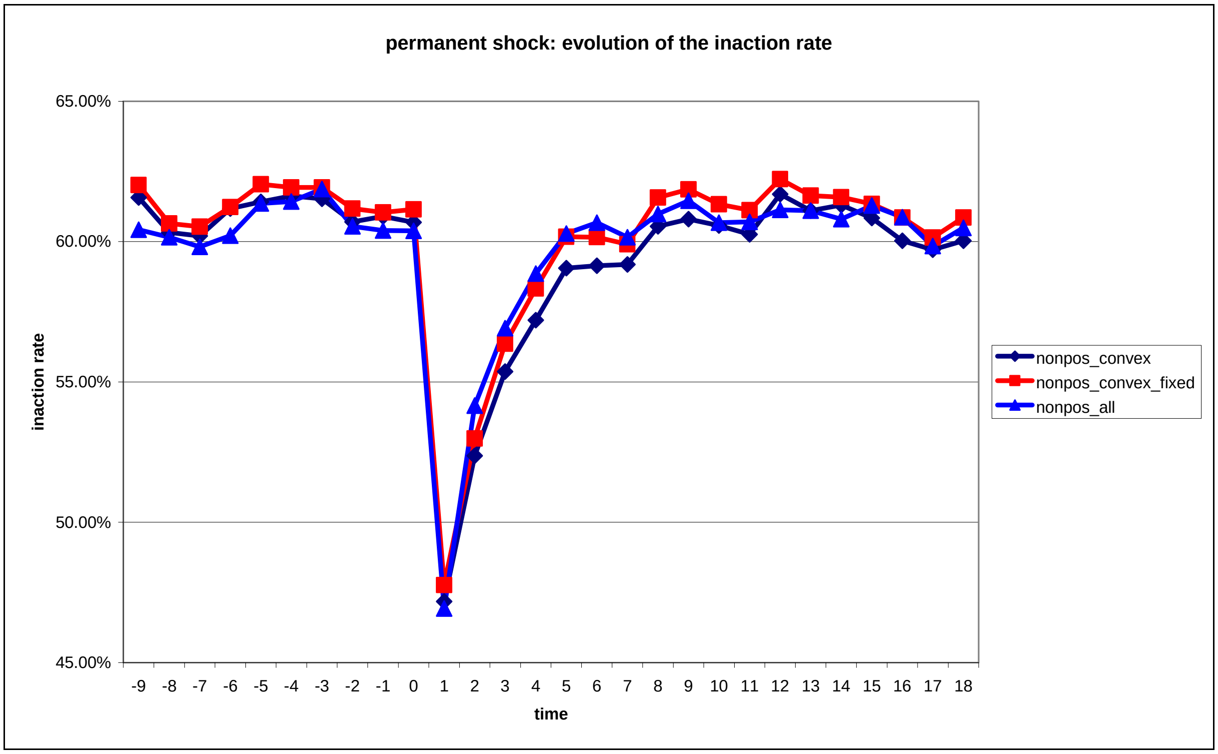

Figure 13. The effect of a permanent profitability shock on aggregate the proportion of inactive firms.

When tracking the inaction rates under different cost structures, one may ask how inaction occurs at all when there are only convex costs of adjustment. Indeed, standard investment models with convex adjustment cost suggest that in this case there is no inaction at all. However, if one makes distinction between replacement investment and new investment, then *inaction in new investment* can emerge easily, especially if the convex cost component is high. The reason of this is that convex costs make the shock-investment relationship flat, and therefore for a large interval of shocks the optimal *gross* investment rate will be between 0 and the depreciation rate, meaning that the *new* investment rate is zero in these cases. This phenomenon is also observable on *Figure A/4*. in *Appendix A*, where the optimal shock-investment relationship is depicted for the case of "only convex costs". With a relatively modest convex cost parameter (in that figure $\gamma = 0.2$), the inaction rate of new investments is already visible. The case that is discussed here has much higher convex cost parameter: $\gamma = 0.7605$, therefore the shock-investment relationship is much flatter, so it is not a surprise that the inaction in *new* investment rates is as high as 60% in steady state.

All of these experiments suggest that there are important aggregate implications of the non-convex investment costs. This statement contradicts the main conclusion of *Veracierto (2002)*, who found that there is no aggregate implication of investment irreversibility at the plant level. But this difference can be fully explained with the difference between the magnitudes of identified profitability shocks. In this paper, the standard deviations of the aggregate and idiosyncratic profitability shocks are 0.1092 and 0.3155, much larger than the standard deviation of the productivity shock in *Veracierto (2002)*: 0.0063.[50] As a consequence of this, the irreversibility constraint is effective for many observations in the simulations,

[50] There are important differences between the identification of these standard deviations. First and most importantly, Veracierto (2002) deals with *productivity* shocks, and identifies them from observed Solow-residuals. On the other hand, our key concept is the *profitability* shock, which incorporates Veracierto's productivity shock, and many other sources of shocks: labor shares, demand elasticities, wages.

while it is never binding for Veracierto; as he notes, this is the ultimate reason of the opposite conclusions. Studies with comparable shock standard deviations (*Coleman, 1997*, *Faig, 1997*, and *Ramey-Shapiro, 1997*) all find important aggregate effects of irreversible investment.

8. Conclusions

This paper estimates the structural parameters of a firm-level investment model with a rich structure of adjustment costs, and analyzes whether non-convex adjustment cost components have any effect on the aggregate investment dynamics.

The most important **firm-level results** can be summarized as follows:

- all types of adjustment costs considered here are significant, in the sense that the model with all kinds of adjustment costs leads to a much better fit than that having only convex adjustment cost;
- the estimated adjustment cost parameters are in line with estimates prepared with similar methods in the literature.

On the aggregate level, the main focus is on evaluating the possible effects that monetary policy can have on aggregate investment dynamics. To do so, I assume that monetary policy affects the aggregate profitability shock that hits the firms. Since it is highly uncertain (and should be a subject of further research) how certain monetary policy decisions translate into aggregate profitability shocks, the analysis comes down to the analysis of how aggregate profitability shocks influence aggregate investment dynamics. The **aggregate level results** are the following:

- the investment-shock relationship is highly different when investigated at the aggregate level than at the firm-level (a result that is robust across adjustment cost specifications). The main difference is that the shock-investment relationship is found to be highly non-linear at the firm-level, whereas at the aggregate level one can not detect a similar phenomenon;
- aggregate profitability shocks, when unanticipated, have moderate effects on aggregate investment dynamics: an aggregate shock bigger than 10% induces an immediate response of 1-2% in aggregate gross investment rate, while the cumulative effect is not more than 4-5%;
- on the other hand, anticipated aggregate profitability shocks have much bigger effect on aggregate investment rates: an anticipated aggregate shock of 10.92% triggers a 7.2%-11.5% immediate increase in aggregate gross investment rate, while the cumulative effect is 24.1-24.3% over the next 10 periods;
- aggregate investment responses are different under convex and non-convex investment cost structures: when there are non-convexities in the investment cost function, average responses are bigger. Therefore, while non-convexities in the adjustment cost function make investment more lumpy at the firms level, at the same time they lead to a more flexible response to shocks at the aggregate level;
- a further robust finding across different experiments is that if we have both convex and non-convex adjustment costs, the apparently bigger adjustment takes place on the intensive (as opposed to the extensive) margin. This is I

direct consequence of a more flexible aggregate effect occurring at similar inaction rate.

All of these aggregate effects contradict *Veracierto (2002)*, who found no aggregate implications of investment irreversibility. The main source of this difference is the fact that the measured variance of the profitability shocks in this paper is relatively large, and this makes the irreversibility constraints occasionally binding.

Based on these, one can be skeptical about the effectiveness of monetary policy on aggregate investment dynamics unless aggregate shocks are anticipated. Since substantial changes in the aggregate profitability shock, if these remain unanticipated, seem to lead to only moderate changes in aggregate investment dynamics, there are two possibilities for monetary policy to have large influence on aggregate investment: (1) if monetary policy sends positive permanent profitability shocks that are fully anticipated and credible; (2) if it delivers huge unanticipated aggregate profitability shocks. Finally, I found in all contexts that the presence of non-convex investment costs make the response in aggregate investment rates quicker.

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Appendix A

Investment functions with different simple cost structures

Figure A/1 illustrates the investment-shock relationship in the **cost-free case**. $(F=0,\gamma=0,p=1)$. We see that investment is non-zero whenever the shock is non-zero, that is, we have instantaneous adjustment. We see that this function is slightly convex even in this case. This reflects the law of diminishing returns for the capital: when a large shock increases the marginal value of capital (q), we need a proportionally higher increase in the capital stock to restore the optimality condition of $q=1/\beta$; therefore the shock-investment relationship is slightly convex: $\hat{\psi}_1=2.5233$, $\hat{\psi}_2=0.4384$, $\hat{\psi}_3=-2.5151$. We also see that as investment is cost-free, investment rates are relatively high even for small shocks: a typical profitability shock (of one standard deviation, $\tilde{a}=0.0822$) triggers a 21.04% (2.5233*0.0822 + 0.4384*0.0822*0.0822) investment rate.

Figure A/2: the case of **partially irreversible** investment $(F=0,\gamma=0,p=0.95)$. Observe that irreversibility creates an inaction region, but the investment function remains continuous: small investments are still possible. Because of the inaction region, the shock-investment relationship became more convex, and as capital sales became more expensive, we need very large negative shocks (<-60%) to induce negative investments. The estimated parameters of the usual reduced form regression $\hat{\psi}_1=0.8520$, $\hat{\psi}_2=0.3928$, $\hat{\psi}_3=-0.5564$. Convexity is stronger (the relative size of $\hat{\psi}_2$ increased), and the absolute value of the parameters decreased, so effect of profitability shocks is much smaller (a 1 standard deviation profitability shock, $\tilde{a}=0.0822$ leads to 7.27% = 0.8520*0.0822 + 0.3928*0.0822*0.0822 investment).

Figure A/3: we have **convex cost** of investment $(F=0,\gamma=0.2,p=1)$. We see that investment is instantaneous (any shock leads to investment activity), but as the marginal cost increased, it is of smaller magnitude (the function became flatter). Estimated reduced regression parameters: $\hat{\psi}_1=0.4657$, $\hat{\psi}_2=0.0672$, $\hat{\psi}_3=-0.2557$, so a 1 standard deviation profitability shock leads to an investment rate of 3.87% (0.4657*0.0822 + 0.0672*0.0822*0.0822), which is much smaller than in the frictionless case.

Figure A/4: investment function with **fixed costs** $(F=0.001,\gamma=0,p=1)$. This is basically the same as in the frictionless case, but firms do not undertake small investments, when the net gain is smaller than fixed costs. So fixed costs create an inaction region, and also lead to discontinuity (as no small investment activity is observed). The estimated parameters of the reduced form regression (9) are: $\hat{\psi}_1=2.4475$, $\hat{\psi}_2=0.4423$, $\hat{\psi}_3=-2.4165$, which is very similar to the frictionless case. This result is intuitive, as the graph of the investment function has not changed dramatically. A 1 standard deviation profitability shock leads to an investment rate of 20.42% (2.4475*0.0822 + 0.4423*0.0822*0.0822), which is also similar to the frictionless case.

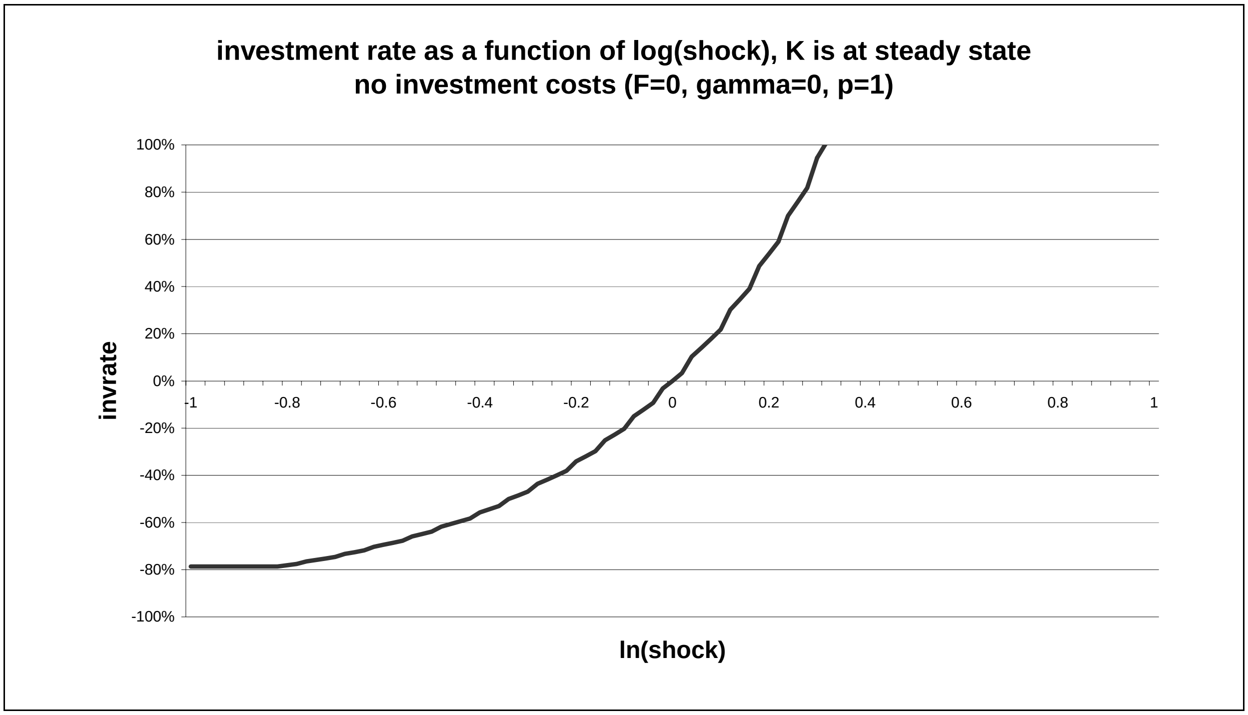

Figure A/1. The investment function in the costless case

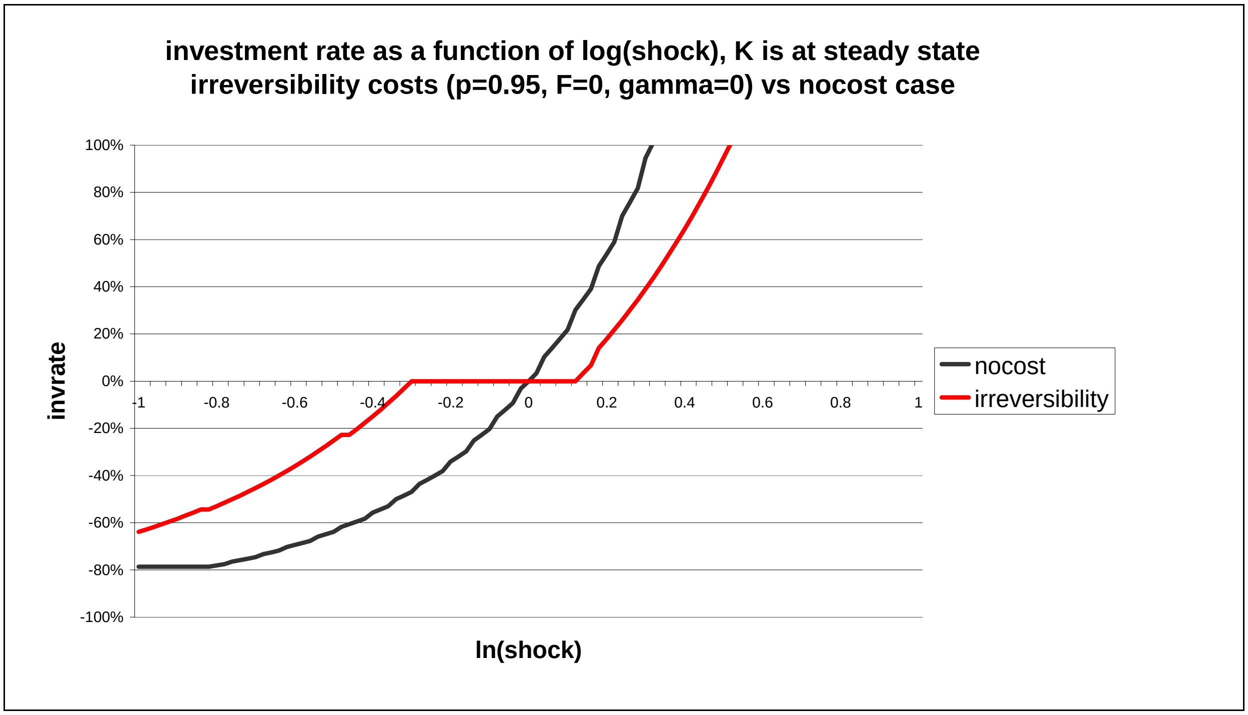

Figure A/2. The investment function if there is (partial) irreversibility

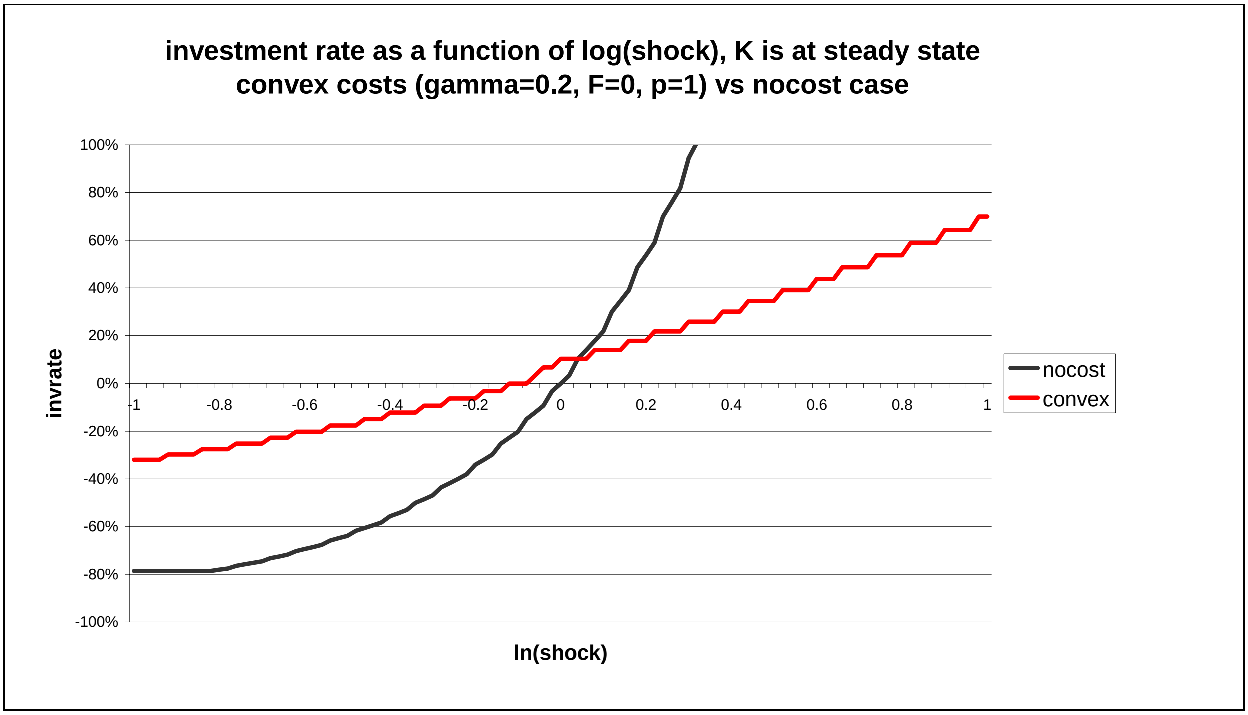

Figure A/3. The investment function if there is a convex cost of investment

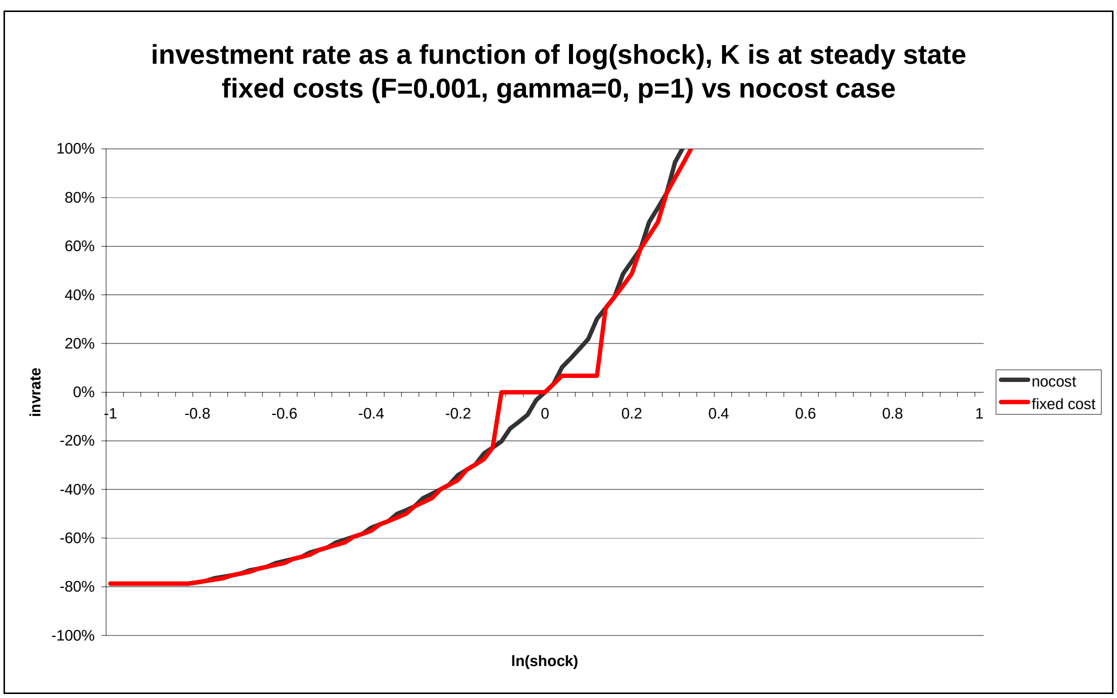

Figure A/4. The investment function if there is a fixed cost of investment

Appendix B

To further investigate the estimated θ parameter, I also estimated it for the different manufacturing sub-sectors (this time I only used the IV method on the shifted log-log model). It is observable on *Figure B/1* that in those sectors that we think to be relatively more capital-intensive (chemical industry, machinery), I obtain somewhat larger estimates, with the interpretation that profit is more responsive to capital in these sectors. *Figure B/1* also suggests that outliers do not have large impact on the relative size of estimated industry-specific θ-s, a similar finding that was also true for the whole manufacturing industry.

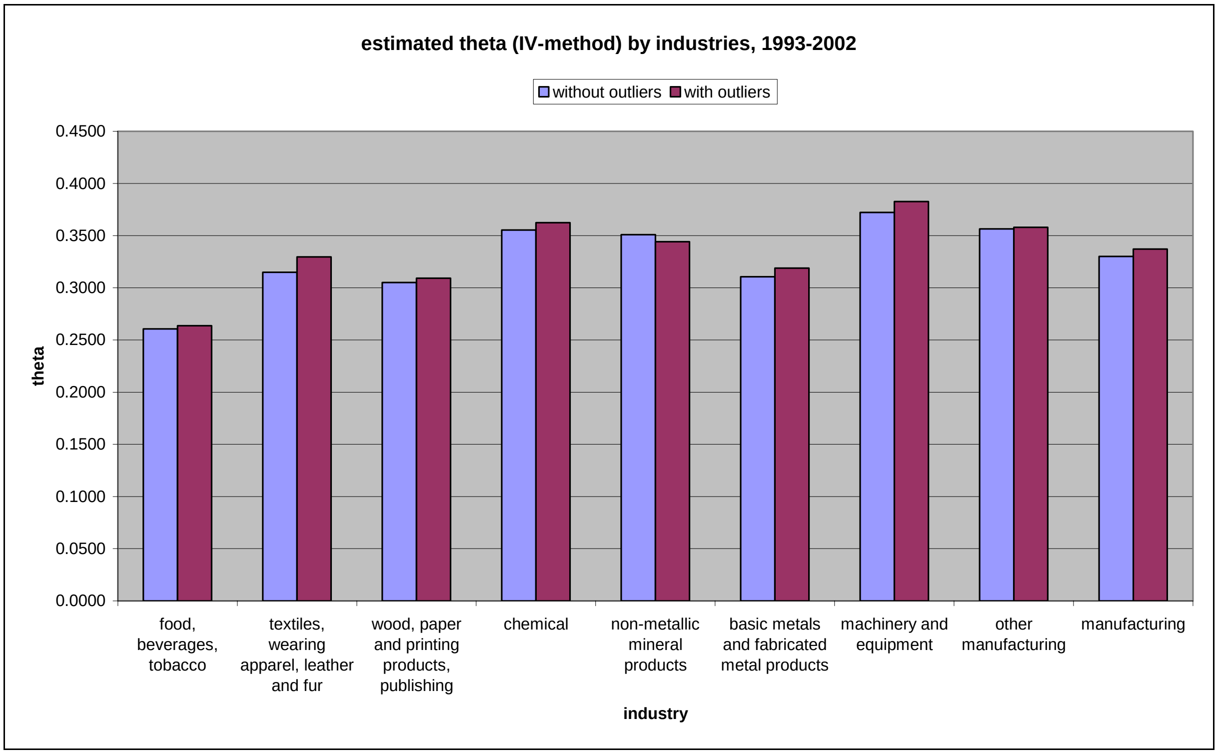

Figure B/1. Estimated θ (IV-method) by manufacturing industries.

To investigate the stability of the estimated parameters over time, I divided the data set to two further sub-samples: one early sub-sample containing observations between 1993-1997, and another sub-sample with observations between 1998-2002. It is observable on *Figure B/2* that the estimates on the whole sample (1993-2002) are mainly driven by the estimates between 1998-2002, while the estimates based on the early period of 1993-97 are relatively more different. There are two possible explanations of this:

(1) Observations in the early years (1993, 1994) are noisy; a similar hypothesis was set up by *Kátay-Wolf (2004)*;

(2) Firms behaved differently during the years of transition than later.

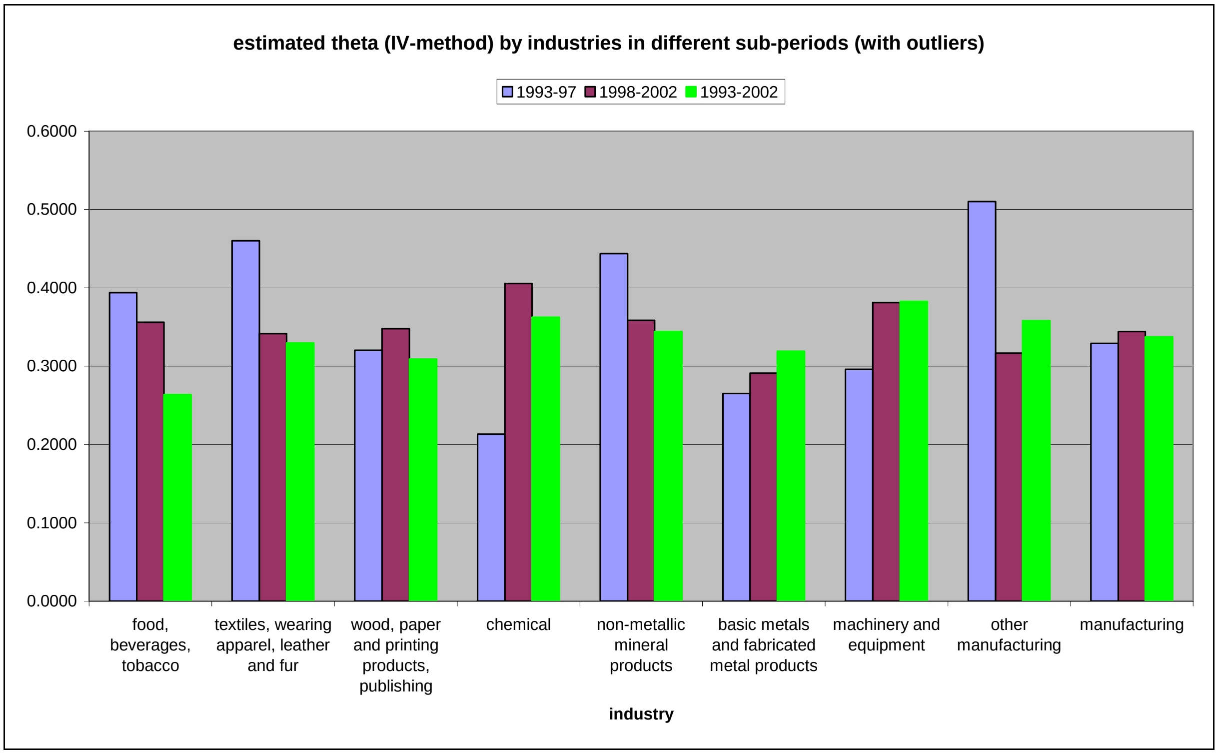

Figure 2/B. Estimated θ (IV-method) by industries in different sub-periods.

Appendix C

The responsiveness of matched parameters to the structural cost parameters

In *Section 3* it is claimed that the reduced-regression parameters do not contain any information based on which one could identify F, the fixed cost of investment. The main argument behind this is that in the frictionless case (when $F=0, \gamma=0, p=1$), changing F does not lead to changes in the estimated reduced regression parameters. This claim is also intuitive from *Figure A/4* in *Appendix A*.

This is, however, only a "local" finding for the frictionless case, and it still remains to be seen that something similar happens for changes in the fixed cost parameter when the other types of costs (convex, irreversibility costs) are non-zero. To investigate this, my focus is on the following matrix:

$$B=\begin{bmatrix} \frac{\partial \phi_1}{\partial F} & \frac{\partial \phi_1}{\partial \gamma} & \frac{\partial \phi_1}{\partial p} \\ \frac{\partial \phi_2}{\partial F} & \frac{\partial \phi_2}{\partial \gamma} & \frac{\partial \phi_2}{\partial p} \\ \frac{\partial \phi_3}{\partial F} & \frac{\partial \phi_3}{\partial \gamma} & \frac{\partial \phi_3}{\partial p} \end{bmatrix}.$$

When using indirect inference, it is common to refer to this matrix as the *binding matrix*. It shows how sensitive are the matching parameters to the structural parameters to be estimated. In fact, as *Gourieroux et al. (1996)* show, the variance-covariance matrix of the estimated structural parameters is proportional to $\left[B'\hat{\Omega}^{-1}B\right]^{-1}$, where $\hat{\Omega}$ is simply the variance-covariance matrix of the matching parameters (reduced-regression parameters in our case), as estimated from the data.

Now it is easy to see why it is a problem if the reduced regression parameters are not sensitive to one of the structural parameters. In the frictionless case, I find (locally) that $\frac{\partial \phi_1}{\partial F}$, $\frac{\partial \phi_2}{\partial F}$, $\frac{\partial \phi_3}{\partial F}$ are zero (or they are very close to that when calculated numerically), so the first column of the binding matrix is zero, so the estimated standard error of the fixed cost parameter is infinite.

Since it is impossible to prove globally that one particular column of the binding matrix is (sufficiently close to) zero, I numerically investigated this binding matrix for some triplets of the structural cost parameters. For example, for $F=0.0001, \gamma=0.22, p=0.991$ (this is the estimated cost structure in *Section 6*) the binding matrix is

$$\begin{bmatrix} -35 & -0.315 & 1.85 \\ 75 & -0.050 & -2.05 \\ 30 & 0.245 & -1.50 \end{bmatrix}.$$

These numbers have to be compared according to the scaling of the model. For example, one would think that $\frac{\partial \phi_1}{\partial F} = -35$ is relatively high (in absolute terms), but taking into account the scaling, a typical change in F is very small: a 1% increase in F (0.000001) would decrease ϕ_1 by 0.000035 (approximately). In contrast, as a result of a 1% increase in γ (0.0022), ϕ_1 would decrease by 0.000690 (approximately), a 20-times bigger effect. And also, a 1% increase in the extent of irreversibility (i.e. the change of p from 0.991 to 0.99091, by 0.00009) would decrease ϕ_1 by 0.000167, a 5-times bigger effect again.

In other words, while the entries in the first column of the binding matrix seem to be bigger (in absolute terms), they are not sufficiently bigger to bring down the estimated standard error of F to such a low level so that the estimated F would become significant. Indeed, if I try to estimate the structural cost parameters only on the basis of the reduced regression, then the estimated fixed cost parameter is insignificant.

In this case, the introduction of the inaction rate (and skewness) ensures the identification. If we include these into the set of the matching parameters, then the first column of the binding matrix (whose shape is now *5x3*) is

$$\begin{bmatrix} -35 \\ 75 \\ 30 \\ 45000 \\ 680 \end{bmatrix}.$$

It is intuitive that $\frac{\partial inaction}{\partial F}$ is positive: increasing fixed costs obviously increase the inaction rate. But now the magnitude of this positive parameter is enough to bring down the estimated standard error of the fixed cost to a level when the estimated fixed cost becomes significant.

I did these numerical calculations for a wide range of structural parameter sets (including all parameter sets that are reported as estimated cost parameters anywhere in the paper), and I found that the results were as I explained here for $F = 0.0001, \gamma = 0.22, p = 0.991$. So it seems to be the case that it is a global phenomenon that the reduced regression alone does not identify (or at least poorly identifies) the fixed cost parameter, and it is the inaction rate (and skewness) that brings identification to this type of cost parameter.