MAGYAR NEMZETI BANK

MNB WORKING PAPERS

2010/2

ÁDÁM REIFF

Firm-level adjustment costs and aggregate investment dynamics – Estimation on Hungarian data

Firm-level adjustment costs and aggregate investment dynamics – Estimation on Hungarian data

April 2010

MNB Working Papers 2010/2

Firm-level adjustment costs and aggregate investment dynamics – Estimation on Hungarian data

(Cégszintű beruházási költségek és az aggregált beruházások alakulása – becslés magyar adatokon)

Written by: Ádám Reiff*

Published by the Magyar Nemzeti Bank

Szabadság tér 8–9, H–1850 Budapest

http://www.mnb.hu

ISSN 1585 5600 (online)

* Researcher, Magyar Nemzeti Bank, e-mail: reiffa@mnb.hu.

Contents

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 is because the model is calibrated to have the same proportion of inactive (i.e. non-investing) firms under convex and non-convex adjustment costs, but the average size of new investment of active firms is higher under non-convex adjustment costs.

JEL Classification: E22.

Keywords: Capital Adjustment Costs, Lumpy Investment, Irreversible Investment, Aggregation.

Összefoglalás

A tanulmány magyar adatokon becsli meg egy cégszintű beruházási modell általánosan specifikált beruházási költségfüggvényének a paramétereit, és azt vizsgálja, hogy a költségfüggvény nem-konvex tényezői befolyásolják-e a makroszintű beruházásokat. A tanulmány arra a kérdésre keres választ, hogy a (például a monetáris politika hatására bekövetkező) makroszintű profitabilitási sokkok különböző makroszintű beruházásokhoz vezetnek-e konvex és nem-konvex beruházási költségek esetén. Az eredmények szerint a nem-konvex költségelemek a cégszintű beruházásokat ragadósabbakká, a makroszintű beruházásokat viszont rugalmasabbakká teszik. Ez utóbbinak az az oka, hogy a modellt úgy kalibráljuk az alternatív – konvex és nem-konvex – költségspecifikációk mellett, hogy az inaktív (nem beruházó) vállalatok részaránya ugyanakkora legyen; nem-konvex igazodási költségek esetén azonban az ugyanakkora részarányú beruházó vállalatok átlagos beruházásmérete nagyobb.

1 Introduction

In Hungary, corporate investment behavior has been mainly investigated on aggregate data (see for example Darvas and Simon 2000, and Pula 2003), and only few studies address this question at the firm level. Among these few studies, Molnar and Skultety (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, number of employees, sales revenues, and to make a correlation analysis of investment activity with various balance sheet measures. Besides this, 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, Katay and Wolf (2004) use the Hungarian Tax Authority'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 the user cost of capital (depending on, among others, the interest rate) affects investment activity.

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

First, as a modeling framework I use the "new investment models"set up by the post-1990 investment literature, incorporating well-documented stylized facts about firm-level investment behavior. The two distinguishing feature of these models is *lumpiness* and *irreversibility*. The empirical studies of Doms and Dunne (1998) and Ramey and Shapiro (2001) showed that firm-level investment is lumpy and irreversible, which phenomena were then incorporated into theoretical investment models by Abel and Eberly (1994) and Bertola and Caballero (1994). This paper uses this class of models, with the main focus being on different types of firm-level investment costs, including fixed, convex and irreversibility costs that firms have to pay when undertaking investment.[3]

A second difference is that while in Katay and 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.

Finally, I extend the framework to investigate aggregate investment behavior, where aggregate investment is defined simply as the sum of firm-level behaviors, by addressing the question of how profitability shocks (driven by monetary policy, for example) can affect aggregate investment. In doing so, I assume that after aggregate profitability shocks that hit the firms, the sum of the firm-level responses to this aggregate profitability shock will determine the behavior of aggregate investment.

Similarly to previous empirical studies, I find that fixed and irreversibility costs of investment are significant at the micro level, which makes investment more lumpy. However, these same non-convex investment costs make aggregate investment *less* lumpy and more responsive to shocks. The intuition is that assuming we calibrate the model to the same inaction rate under convex and non-convex adjustment costs, the same fraction of active firms adjusts by larger amounts under non-convex adjustment costs.

---

[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, so the data set is admittedly not representative.

[3] Stokey (2001) gives a taxonomy of these types of costs, while Bayrakhtar et al (2005) and Cooper and Haltiwanger (2005) empirically estimate the different cost components.

The paper is organized as follows. Section 2 describes the model, and Section 3 discusses estimation strategy.[4] Section 4 is about the data and the main variables, while Section 5 presents the firm-level results. Section 6 contains the aggregate implications, and Section 7 concludes.

[4] A more detailed description of these can be found in Reiff (2006).

2 The model

Let us consider a general investment model,[5] in which firms maximize the present value of their future profits, net of future investment costs:

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

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,[6] the cost of investment I_t is $C(I_t,K_t)$, and β is the firm's discount factor. The capital stock depreciates at rate $\delta > 0$, and the profitability shock is assumed to be a first-order autoregressive process,[7] so the transition equations are

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

$$A_{t+1} = \rho A_t + \varepsilon_{t+1}. \tag{3}$$

Firms 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:[8]

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

and the solution is[9]

$$\beta E_{A'|A} V_K\left(A',K'\right) = C_I(I,K). \tag{5}$$

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).

The timing of the model is the following: at the beginning of the period, 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)). After this, 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 will refer to this sequence of events as the "investment-shock relationship": in each time period, firms respond to profitability shock A with an optimal investment rate I or $I^*(A)$.

The solution in (5) depends on the exact formulation of the investment cost function. In this paper – following Stokey (2001) – I use a general formulation of the investment cost function $C(I_t,K_t)$ with three types of cost components.

---

[5] The model described here is similar to the models in Abel and Eberly (1994) and Stokey (2001).

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

[7] In model simulations, this will be approximated with a first-order Markov-process with the same persistent and volatility.

[8] More precisely, the resulting value function is given by the Bellman equation $V(A,K) = \max_I \left\{ \Pi(A,K) - C(I,K) + \beta E_{A'|A} V(A',K'|A) \right\}$.

[9] V_K is the marginal value of capital for the firm: $\frac{\partial V(A',K')}{\partial K}$, often referred to as Tobin's marginal q.

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

$$C(I,K) = \begin{Bmatrix} FK + \Gamma(I,K), I \neq 0 \\ 0, I = 0 \end{Bmatrix}, \tag{6}$$

where $\Gamma(I,K)$ is the cost of investment other than fixed costs. Note that the fixed cost is assumed to be independent from I, but not from K. 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.

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

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

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, with a minimum value of 0, and also a possible kink at $I = 0$.[10] 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 is discontinuous at $I = 0$ if and only if there is a kink in the $\gamma(I,K)$ function there.

To keep the investment cost function linearly homogenous in (I,K), I define the convex component as $\frac{\gamma}{2}\left(\frac{I}{K}\right)^2 K$. Further, 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 $0 \leq p \leq 1$ must hold. For $p = 1$ there is no irreversibility, and for $p = 0$ investment is completely irreversible.

Finally, following Reiff (2006), I will also distinguish between replacement investment and new investment, which is a generalization of standard investment models. 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:

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

Each of the different cost components have different effects on the optimal investment behavior of individual firms. To see these differences, I solved the model for various simple cases when there is only one type of investment cost, and compare the resulting policy functions (i.e. optimal investment rates as a function of profitability shocks) with the frictionless case. (The corresponding figures are in the *Appendix*.)

Because of *fixed costs*, firms will never make small adjustments whose net gain 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 policy function.

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

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 leads to inaction, but does not lead to discontinuity in the investment-shock relationship.

Finally, *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. This is the well-known partial adjustment mechanism in the presence of convex adjustment costs.

3 Estimation strategy

To estimate the structural cost parameters of the model, I use a modified version of the indirect inference method, first described by Gourieroux and Monfort (1993). With this approach we first 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 the statistics which we match in the theoretical model and in the data. 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:

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

   where i denotes investment rate (I/K), a denotes (log) profitability shock, μ_t is a time-fixed effect and u is a well-behaving error terms, and the variables with tildes denote deviations from plant-specific means. This specification is also used by Cooper and Haltiwanger (2005) and Bayrakhtar et al (2005). The quadratic term (with ϕ_2) is included to capture the non-linearity of the policy function (caused by discontinuity and inaction, both leading to proportionally higher investment rate for larger shocks), while the lagged term (with ϕ_3) captures the lumpiness of investment (i.e. investment reacts to shocks with lags, due to lumpiness).

2. The proportion of inactive (non-investing) firms in the investment rate distribution (the "inaction rate").

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

Therefore, to estimate the parameters of the investment cost function, I first calculate the data moments, denoted by ϕ_0. Note that ϕ_0 is a 5-vector, containing the three reduced form regression coefficients, and also the inaction rate and skewness parameter. Then I simulate the theoretical model for arbitrary cost parameters to obtain the values of the same moments (that is, obtain $\widehat{\phi}(F,\gamma,p)$). Finally, I choose the structural cost parameters (F,γ,p) to minimize the weighted distance between the theoretical and data moments:

$$\left(\phi_0 - \widehat{\phi}(F,\gamma,p)\right)' W^{-1} \left(\phi_0 - \widehat{\phi}(F,\gamma,p)\right) \underset{(F,\gamma,p)}{\longrightarrow} \min, \tag{10}$$

where the weighting matrix W^{-1} is the inverse variance-covariance matrix of the data moments, so any statistics that is estimated with higher precision (i.e. smaller variance) gets higher weight.

4 Data and variables

I use the manufacturing sub-sample of the data set of Katay and Wolf (2004), i.e. the corporate tax returns of double entry book keeping firms between 1992 and 2002 in Hungary. The reason of restricting the attention to the manufacturing industry is to eliminate heterogeneities in investment cost. Other than this, the initial data manipulation is the same, and in most cases I simply adopted the variables constructed there.

The initial data manipulation of Katay and Wolf (2004) consisted of four steps:

1. Observations with missing data in relevant variables (number of employees, capital depreciation) were deleted.
2. Very small firms[11] were deleted.
3. Data were corrected when considered false.
4. Outliers (with respect to cash-flow, depreciation rate, user cost, investment rate, changes in capital stock, employment, sales) were also excluded.

As a result of this initial filtering, they decreased the original panel of 1,269,527 year-observations to a panel of 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.

As a next step, I also excluded the missing observations and outliers with respect to my key variables: investment rate, sales revenue, capital stock, profits, so the final sample size of my data set is 92,293 year-observations.[12]

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 Katay and Wolf (2004), who constructed investment rates from accounting capital data. From the calculated gross investment levels and observed depreciations, Katay and Wolf (2004) constructed a real capital variable with Perpetual Inventory Method (PIM), which I use to measure *capital stock*. Finally, I use operating profit to measure the *profit* of the firms.

[11] Definition of very small firms: if the number of employees is smaller than 2 in any particular year, or if the number of employees is smaller than 5 during three consecutive years.

[12] More precisely, I deleted 18,308 year-observations because of missing investment rate. These were mostly 1992 observations, when initial capital stock was not available. Then I deleted further 118 year-observations because of non-positive sales revenues, and then I deleted those 35 year-observations with missing capital stock. Finally, I deleted 54 year-observations with missing profit data, so this is why the initial sample size of 110,808 decreased to 110,808-18,308-118-35-54=92,293 year-observations.

5 Firm-level results

In this section I describe the calculation of data moments. These are the estimated slope 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 slope parameters of the regression (to which matching will be done).

IDENTIFICATION OF PROFITABILITY SHOCKS

I use the method of Cooper and Haltiwanger (2005) to identify the profitability shocks. Assume that firms have identical, constant returns-to-scale Cobb-Douglas production functions:

$$Y_{it} = B_{it} L_{it}^{\alpha_L} K_{it}^{(1-\alpha_L)}, \tag{11}$$

where labor (L_{it}) is assumed to be adjustable in the short-run and therefore is regarded in the sample with yearly frequency as being optimized, but capital (K_{it}) cannot be adjusted in the short run. We assume constant returns to scale for the sake of simplicity, but the same line of argument holds if the capital share α_K is not equal to the inverse labor share $1-\alpha_L$. Y_{it} is output and B_{it} is a productivity shock, different from the profitability shock A_{it} discussed in (9). 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

$$\Pi_{it} = p_{it}(y_{it}) y_{it} - w_{it} L_{it} = B_{it}^{\frac{1+\xi}{\xi}} L_{it}^{\alpha_L \frac{1+\xi}{\xi}} K_{it}^{(1-\alpha_L)\frac{1+\xi}{\xi}} - w_{it} L_{it} \xrightarrow[L_{it}]{} \max, \tag{12}$$

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

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

Substituting this into the profit function (12), the optimal profit of the firm is

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

We can rewrite (14) as $\Pi_{it}^{*} = A_{it} K_{it}^{\theta}$, where A_{it} is the profitability shock depending on wages, demand elasticity, labor shares and productivity shocks, and $\theta = \frac{(1+\xi)(1-\alpha_L)}{\xi-\alpha_L(1+\xi)}$, a function of the demand elasticity and labor share.

So the firm-level profitability shocks can be written as $A_{it} = \frac{\Pi_{it}^{*}}{K_{it}^{\theta}}$, which can be calculated from the firm-level data set once we have an estimate for θ. The estimation of parameter θ is described later.

The profitability shock calculated this way will be referred to as type-1 shock. But as Cooper and Haltiwanger (2005) and Bayrakhtar et al (2005) point out, this measurement contains observed profits, which is measured with relatively large measurement error. A little algebra shows that there is an alternative way to identify profitability shocks: the optimal profit in (14) can also be written as

$$\Pi_{it}^{*} = w_{it}L_{it}^{*}\left[\frac{\xi}{\alpha_L(1+\xi)} - 1\right] = w_{it}L_{it}^{*}\frac{1}{\theta}\frac{1-\alpha_L}{\alpha_L}, \tag{15}$$

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

$$A_{it} = \frac{\Pi_{it}^{*}}{K_{it}^{\theta}} = \frac{w_{it}L_{it}^{*}}{\theta K_{it}^{\theta}}\frac{1-\alpha_L}{\alpha_L}. \tag{16}$$

Ideally, one need to know the value of the labor share α_L for this computation of the profitability shock. 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: $\log\left(A_{it}\right) = \log\left(\frac{w_{it}L_{it}^{*}}{\theta K_{it}^{\theta}}\right) + \log\left(\frac{1-\alpha_L}{\alpha_L}\right)$, so when subtracting the plant-specific means, the second time-invariant term and α_L disappears. Therefore it is enough to calculate $A_{it} = \frac{w_{it}L_{it}^{*}}{\theta K_{it}^{\theta}}$, which can be done once we have an estimate of θ. The profitability shock calculated this way is referred to as type-2 shock.

Parameter θ is estimated as the "curvature of profit function"from the reduced-form optimal profit equation $\Pi_{it}^{*} = A_{it}K_{it^{\theta}}$. The estimation itself would be straightforward if all observed profits were strictly positive, as in that 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:[13]

1. (Weighted NLLS) 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 big firms on the estimated θ, I weighted the observations with the inverse of 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. (OLS) I shifted the normalized profit of Π_{it}^{*}/R_{it} by a positive constant C to be able to take the log of as many observations as possible, and estimated the linear equation of $\ln\left(\Pi_{it}^{*}/R_{it} + C\right) = \ln\left(A_i\right) + \theta\ln\left(K_{it}\right) + \varepsilon_{it}$ by OLS, assuming that $\ln\left(A_i\right)$ are firm fixed effects.

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

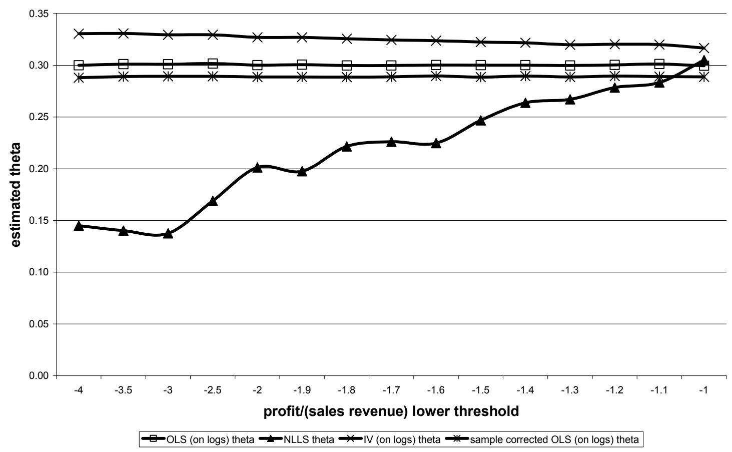
4. (Sample-corrected OLS) I estimated $\ln\left(\Pi_{it}^{*}/R_{it} + C\right) = \ln\left(A_i\right) + \theta\ln\left(K_{it}\right) + \varepsilon_{it}$ by OLS on the same sub-sample as in case of IV estimation.

Figure 1 illustrates the estimated θ-s for different outlier-thresholds. (Outlier-filtering was based on the profit-revenue ration on the left-hand side of the regressions.) 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 parameters C). It is also apparent that IV-estimates are always higher than OLS-estimates, which indicates that capital is

[13] Dropping all observations with negative profits is of course not a solution, as in this case firms hit by negative profitability shocks would be lost with higher probability, leading to selection bias.

endogenous.[14] 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 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, for different outlier-filters



From now on, I will use the IV-based estimate of parameter θ. It is clear from Figure 1 that the IV-based estimate is quite robust for different shift parameters C (fluctuating between 0.3372 and 0.3301), so I accepted the value that is estimated for the largest possible sub-sample (i.e. the one that excludes the lowest number of outliers): $\widehat{\theta} = 0.3372$.

It is instructive to compare the estimated curvature of the profit function with other estimates from different countries. To my knowledge, there are three comparable estimates in the literature. (1) On a balanced panel of US manufacturing firms, Cooper and Haltiwanger (2005) estimated $\theta = 0.50$. For an unbalanced panel of US manufacturing firms, Reiff (2006) estimated $\theta = 0.69$. For a comparable sub-sample as in Cooper and Haltiwanger (2005), he estimated $\theta = 0.46$. (3) Bayrakhtar et al (2005) estimated $\theta = 0.34$ for an unbalanced panel of German manufacturing firms. Therefore the estimate of $\theta = 0.3372$ presented here is well below comparable estimates in the US, but is in line with the findings in Germany. Profits are much more responsive to capital in the US than in Europe.

To further evaluate the reliability of the estimated θ, one can investigate the parameter estimates by industries; Appendix B contains the details. Results indicate that the 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. All of these findings suggest that the overall parameter estimate of $\widehat{\theta}$ is sensible.

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.

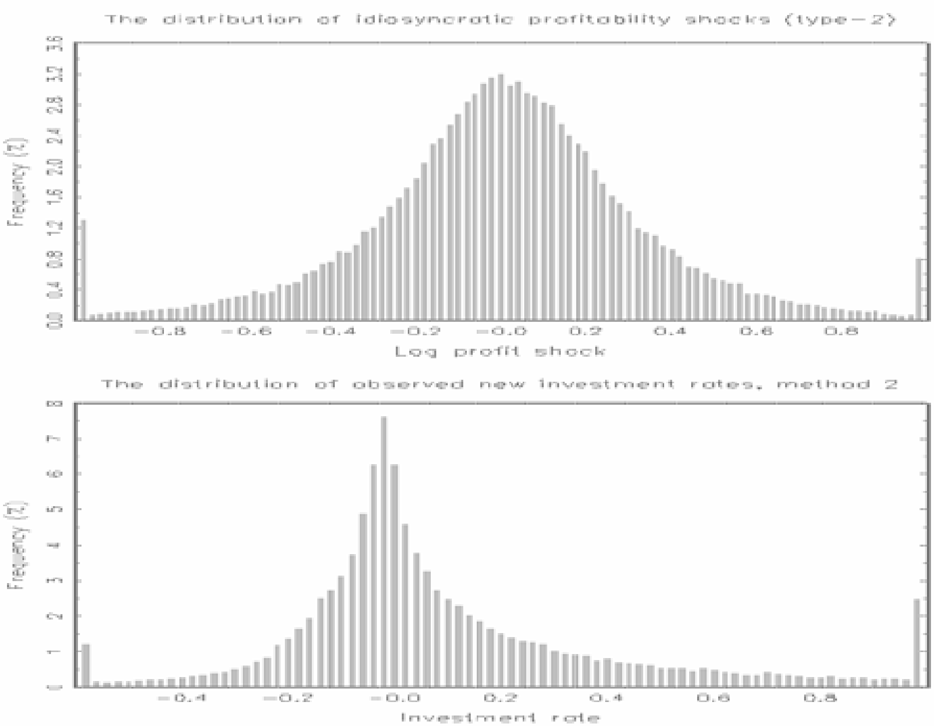
Following Cooper and Haltiwanger (2005), I decomposed the identified profitability shocks to aggregate and idiosyncratic shocks. The purpose of this is to find a relatively simple way to match as closely as possible

[14] The Hausman-test of endogeneity is significant at 1% level for all specifications.

the rich correlation structure (both across firms and over time) of the identified profitability shocks. The aggregate shock is defined as the average of the profitability shocks in the given year t: $A_t = \frac{\sum_{i=1}^{N_t} A_{it}}{N_t}$ (where N_t is the number of firms observed in year t), and idiosyncratic shocks are simply defined as $\varepsilon_{it} = \frac{A_{it}}{A_t}$.

The distribution of the type-2 idiosyncratic profitability shocks is depicted on the first panel of Figure 2. The distribution is symmetric, close to the normal distribution, and has relatively large variance. Table 1 contains the descriptive statistics of type-2 shocks.[15] For comparison purposes, similar statistics for the US (calculated by (Reiff, 2006)) are also reported. Results show that profitability shocks are somewhat more volatile and less persistent in Hungary than in the US.[16]

Figure 2
Distributions of profitability shocks and new investment rates



MEASUREMENT OF NEW INVESTMENT RATES

When specifying the investment cost function, I distinguished replacement investment and new investment. Replacement investment (up to the depreciated part δK of existing capital stock) is cost-free, the capital adjustment costs are only applicable for the "new investment"in excess to the replacement investment.

I measured new investment with three alternative ways:

[15] Type-1 shocks are much more noisy (a consistent finding with the results of Cooper and Haltiwanger (2005) and Bayrakhtar et al (2005)), so I do not report the statistics of these.

[16] The time series of the estimated aggregate profitability shocks is also intuitive: there is a big decline in the log aggregate profitability between 1994-96 (from +10.9% to -9.2%), coinciding with the stabilization package of 1995. After 1996, the log aggregate profitability gradually increases to +14.1% in 2002.

Table 1

Basic statistics of identified (type-2) profitability shocks in Hungary and US

	Hungary	US (Reiff 2006)
Aggregate shock standard deviation	0.0993	0.0822
Aggregate shock autocorrelation	0.6932	0.9325
Idiosyncratic shock standard deviation	0.3594	0.2891
Idiosyncratic shock autocorrelation	0.3685	0.6410

1. *Method 1.* Here I use the average depreciation rate ($\delta = 7\%$, calculated for the US) to separate replacement and new investment in the following way:
   - If the observed gross investment rate is bigger than δ, then I assume that investment up to a rate of δ is (free) replacement investment, and the investment in excess to this ($i^{gross} - \delta$) is the costly new investment.
   - If the observed gross investment rate is positive, but smaller than δ, then all the investment activity is assumed to be replacement investment, and new investment is 0.
   - If the observed gross investment rate is negative, then all of this is assumed to be new (dis-) investment. The reason is that if firms did have some replacement investment, then the necessary disinvestment would be larger and more expensive.
2. *Method 2.* Here 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.
3. *Method 3.* This is similar to Method 1, with the difference being that disinvestment threshold is not the overall depreciation rate δ, but it is the actual depreciation rate reported by the firms. So in this case the calculation of the new investment rates is similar to method 1, but instead of delta we use the observed depreciation/capital ratio as thresholds for replacement and new investment.

The measurement of the new investment rate is of course crucial for the identification of investment cost parameters. Therefore I show the resulting investment rate distributions and basic investment statistics for all three alternative definitions. Panels 2-4 of Figure 2 show the resulting new investment rate distributions, while Table 2 contains the descriptive statistics for the three alternative methods. For comparison purposes, Table 2 also contains the same moments calculated for the US manufacturing data set from Reiff (2006) – the moments are surprisingly similar.

It is apparent from Figure 2 and the third column of Table 2 that when calculating the new investment rates with method 2, there are far too many negative investment rates, indicating that the assumption of each firm doing replacement investment in each year is not realistic. However, the investment rate distribution and the implied data moments are quite similar in methods 1 and 3. Further, the measured Hungarian investment rates are much more volatile than in the US: the proportion of disinvestments and spikes are larger in Hungary according to all alternative methods, and the standard deviation of firm-level investment rates is also approximately double of what is measured in the US.

ESTIMATION OF THE SHOCK-INVESTMENT RELATIONSHIP

With the profitability shocks and investment rates, now I estimate the reduced-form shock-investment relationship of equation (9), based on which I to identify the structural cost parameters. The specification that

Table 2

Descriptive statistics of alternative new investment rate distributions

	Hungary			US (Reiff (2006))
	Method 1	Method 2	Method 3	
Prop of disinvestments	10.67%	47.15%	10.50%	2.45%
Prop of small investments	39.59%	32.71%	49.64%	42.35%
Prop of spikes (I/K>20%)	35.00%	33.34%	27.72%	19.89%
Mean of new investment	22.30%	9.17%	13.39%	11.84%
St.dev. of new investment	31.28%	31.35%	28.00%	15.10%
Skewness	0.9559	1.1272	1.4984	1.2182

I estimate is a quadratic one between investment and profitability shocks, with lagged shocks also included. The quadratic term is included to capture non-linearity (because of fixed costs and irreversibility), while the lagged variable captures lumpiness (also because of either irreversibility or fixed costs).

Table 3

Estimated reduced regression parameters (with standard errors in parenthesis) for alternative methods to measure new investment

	Hungary			US (Reiff (2006))
	Method 1	Method 2	Method 3	
$\widehat{\phi}_1$	0.1516 (0.0098)	0.1660 (0.0105)	0.1531 (0.0095)	0.1150 (0.0085)
$\widehat{\phi}_2$	0.0375 (0.0218)	0.0863 (0.0239)	0.0817 (0.0218)	0.0822 (0.0147)
$\widehat{\phi}_3$	-0.0349 (0.0077)	-0.0355 (0.0082)	-0.0332 (0.0074)	-0.0251 (0.0081)
Number of firms	12,918	12,984	12,984	1,554
Number of observations[17]	50,470	51,485	51,485	23,413

Table 3 reports the estimated parameters of this regression for alternative measurements of the 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 $\widehat{\phi}_2$, which is much lower for method 1 than for alternative methods.

Table 3 also contains the estimated parameters of the same reduced-form regression for US data, as reported by Reiff (2006). Hungarian moments have the same sign and similar magnitude as the US moments.

These estimated parameters (together with observed inaction rate and observed investment rate distribution skewness) will be used to identify the structural cost parameters of the theoretical model via the indirect inference method.

ESTIMATION OF STRUCTURAL COST PARAMETERS

Structural cost parameters are identified by matching the parameters of the theoretical shock-investment relationship, the theoretical inaction rate and the theoretical investment rate distribution skewness to data

[17] The number of observations is larger when we measure investment rate with methods 2-3. The reason is that in case of method 1 the number of investment outliers (defined as investment rates above 125%) is much larger.

moments reported in the previous two subsections. Theoretical parameters are obtained by simulating the theoretical model for arbitrary cost parameters (F, γ, p). This simulation involves the following steps:

1. Choose arbitrary cost parameters (F, γ, p).
2. Solve for the value and policy function of the theoretical model. For this, I use value function iteration on fine grids with respect to the state variables (A, K). In case of shocks I assume that they have the same distribution as observed in data. In particular, I assume AR(1) shocks with the same unconditional standard deviation and persistence as observed in data (see Table 1). Regarding the other parameters, I also assume $\beta = 0.95$ and $\delta = 0.07$, where the latter is an average depreciation rate reported by Katay and Wolf (2004).[18]
3. With the policy function, 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 to simulate the capital paths of the hypothetical firms in the artificial data set, and calculate the corresponding investment rates.
4. Estimate the reduced-form shock-investment relationship in the simulated data set, and also the inaction rate and the investment rate distribution skewness.
5. Do this for several parameter vectors (F, γ, p), and choose the one for which the weighted distance between simulated and data moments is the smallest.

As it is clear from Table 4, if the cost parameters are $F = 0.0001$, $\gamma = 0.22$ and $p = 0.991$, the simulated reduced-regression parameters, inaction rate and investment rate distribution skewness are quite close to their corresponding values in the data. In fact I found that the distance between theoretical and data moments (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.

Table 4

Data and theoretical moments for estimated cost parameters

	Data moments	Theoretical moments[19]
Reduced regression ϕ_1	0.1531	0.1207
Reduced regression ϕ_2	0.0817	0.0540
Reduced regression ϕ_3	-0.0332	-0.0669
Non-positive investments	60.15%	60.02%
Skewness	1.4984	1.4872

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 2), the estimated convex cost is relatively high ($\hat{\gamma} = 0.761$), but the distance of the simulated statistics from their observed counterparts is also quite high (150.14). Allowing for fixed costs (column 3), this distance decreases substantially to 50.87, which indicates that the match of the model improved considerably. The estimated convex cost parameter also declines to $\hat{\gamma} = 0.479$. This is because increasing fixed costs take on the role of convex costs, i.e. we do not need that much convexity any more if there are also fixed costs. Finally, further generalization of the cost structure by allowing for irreversibility costs (column 4) leads to further decrease in the distance between theoretical and data moments (now the decrease is approximately 16%). In this case increasing irreversibility costs are the ones that partially take on the role of fixed and convex costs, while improving the overall match.

[18] In principle, these parameters could also be estimated from data, but this would increase considerably the computation time.

[19] For structural cost parameters $F = 0.0001, \gamma = 0.22, p = 0.991$.

Table 5

Estimated structural cost parameters (and standard errors)

	Only convex costs	Convex + Fixed costs	All types of costs
$\widehat{F}$	0 (-)	1.19E-04 (0.07E-04)	1.00E-04 (0.18E-04)
$\widehat{\gamma}$	0.761 (0.002)	0.479 (0.039)	0.220 (0.033)
$\widehat{p}$	1.000 (-)	1.000 (-)	0.991 (0.002)
Distance	**150.14**	**50.87**	**42.61**

The estimated fixed cost parameter, though being significant, is numerically small, even if one compares it to similar estimates of Cooper and 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 capital when investment rate is one percent.[20]

The estimated convex cost parameter is much closer to comparable estimates, with Cooper and Haltiwanger (2005) reporting an estimate of 0.049, while Bayrakhtar et al. (2005) estimate $\gamma = 0.532$.

The estimated irreversibility parameter is significantly different from 1, but indicates small degree of irreversibility, a similar phenomenon that was also observed by the other two comparable studies (Cooper and Haltiwanger (2005) estimated 0.975, while the initial version of Bayrakhtar et al (2005) reported $p = 0.902$). It is a common finding that structural irreversibility estimates are much lower than direct irreversibility estimates (Ramey and Shapiro (2001) estimated an average discount of 72% on capital sales, while Reiff (2004) found a discount rate of approximately 50%).

In order to evaluate the relative magnitude of the different adjustment costs, it is useful to calculate the different types of costs of some specific investment episodes. For example, if a firm disinvests by 5%, then it has to pay a fixed cost of 0.0001, a convex cost of $\frac{0.22}{2}(-0.05)^2 = 0.000275$, and also an irreversibility cost of $(1-0.991)0.05 = 0.00045$. So the total adjustment cost is 0.000825, or 1.65% of the total frictionless sales price (which would be 1*0.05=0.05). Of this, 12.1% is fixed cost, 33.3% is convex cost, and 54.6% is irreversibility cost. So irreversibility in fact is not that small.

On the other hand, if a firm engages in an average investment project observed from data (when investment rate is 13.39%), then it has to pay a fixed cost of 0.0001, a convex cost of $\frac{0.22}{2}0.1339^2 = 0.001972$, so of all adjustment costs, 95.2% is convex costs and 4.8% is fixed costs. Obviously, convex costs become more and more important as the absolute size of investment increases.

[20] Since the model is normalized to the purchase price of capital, an investment rate of 1% costs 0.01.

6 Aggregate results

In this section 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), who focussed on the differences between micro- and macro-level phenomena, and found that even if there is asymmetric adjustment at the micro-level, if firm-specific shocks are not perfectly harmonized, this asymmetry vanishes at the macro-level because of aggregation. *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. This way one can judge whether non-convex cost components matter at the aggregate level. 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, and finds that irreversibility is unimportant for the aggregate variables. Cooper and Haltiwanger (2005) also find that a model with only convex adjustment costs fits aggregate data reasonably well.

COMPARISON OF FIRM-LEVEL AND AGGREGATE SHOCK-INVESTMENT RELATIONSHIP

To compare firm-level and aggregate investment dynamics, I estimated the reduced-form regression (9) ($\widetilde{i}_{it} = \phi_0 + \phi_1 \widetilde{a}_{it} + \phi_2 \widetilde{a}^2_{it} + \phi_3 \widetilde{a}_{i,t-1} + \mu_t + u_{it}$) for both firm-level and aggregate data, simulated under various cost structures. For the estimation, I used simulated data (based on the solution of the theoretical model), where the number of firms is $N = 7,000$ and the number of time periods is $T = 28$.[21] The estimated parameters under the different scenarios are in Table 6.

Table 6

Aggregate and firm-level reduced regression parameters under different cost structures

	Only convex costs	Convex + Fixed costs	All types of costs
	Aggregate results (N=28)		
$\widehat{\phi}_1$	0.0655 (0.0030)	0.0877 (0.0042)	0.1281 (0.0067)
$\widehat{\phi}_2$	0.5069 (0.3817)	0.8029 (0.5353)	1.3125 (0.8572)
$\widehat{\phi}_3$	-0.0195 (0.0030)	-0.0307 (0.0042)	-0.0554 (0.0067)
	Firm-level results (N=28*7,000)		
$\widehat{\phi}_1$	0.0613 (0.0001)	0.0822 (0.0001)	0.1207 (0.0002)
$\widehat{\phi}_2$	0.0224 (0.0002)	0.0357 (0.0003)	0.0540 (0.0005)
$\widehat{\phi}_3$	-0.0265 (0.0001)	-0.0389 (0.0001)	-0.0669 (0.0001)

The results show that the parameters of the linear terms (ϕ_1 and ϕ_3) are similar on the aggregate and the firm-level: they increase in absolute terms as we allow non-convex cost components, and they are close to each other. 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, which result is robust across different cost specifications.

[21] These numbers were chosen to match the corresponding numbers reported by Cooper and Haltiwanger (2005).

COMPARISON OF AGGREGATE EFFECTS UNDER CONVEX AND NON-CONVEX INVESTMENT COSTS

To analyze the aggregate implications of the non-convex costs of investment, I compare the behavior of aggregate variables after different types of aggregate shocks. In particular, I will consider the following three types of aggregate shocks:

1. (*Permanent shock*) At $t = 1$, a one standard deviation aggregate shock hits. So the simulated aggregate shock is 0 until $t = 0$, and it is 0.1092 from $t = 1$ onward. The idiosyncratic shocks are drawn randomly from the empirically observed distribution.
2. (*Transitory shock*) At $t = 1$, a one standard deviation shock hits. So the simulated aggregate shock is 0 until $t = 0$ and after $t = 1$, but it is 0.1092 at $t = 1$. Idiosyncratic shocks are again drawn from the empirically observed distribution.
3. (*Credible permanent shock*) Similarly to the first experiment, a one standard deviation aggregate shock hits at $t = 1$. The only difference is that in this case firms know that the shock will remain at this level forever (in the first experiment they expected it to return to 0).

In all of the three experiments, I will compare the aggregate investment path under three different cost structures, which correspond to the three cases estimated in Tables 5-6: the first is when there are only convex adjustment costs (labeled as "convex"), the second is when there are convex and fixed costs (labeled as "convex + fixed"), and the third is when there are convex, fixed and irreversibility costs (labeled as "all").

The first row of Figure 3 illustrates the effect of the *permanent* profitability shock on the aggregate investment rates.[22] 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 years. The reason of this moderate effect is that firms anticipate the aggregate profitability shock to go back to its initial level of 0.

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. Alternatively, when all types of costs are present, convex costs are relatively low and non-convex costs are relatively high, so large investment episodes are relatively cheap. So it is intuitive that in case of both convex and non-convex costs (case "All 3 types"in Figure 3), the immediate response to the positive profitability shock is larger and quicker (i.e. the impulse response function becomes zero relatively earlier).

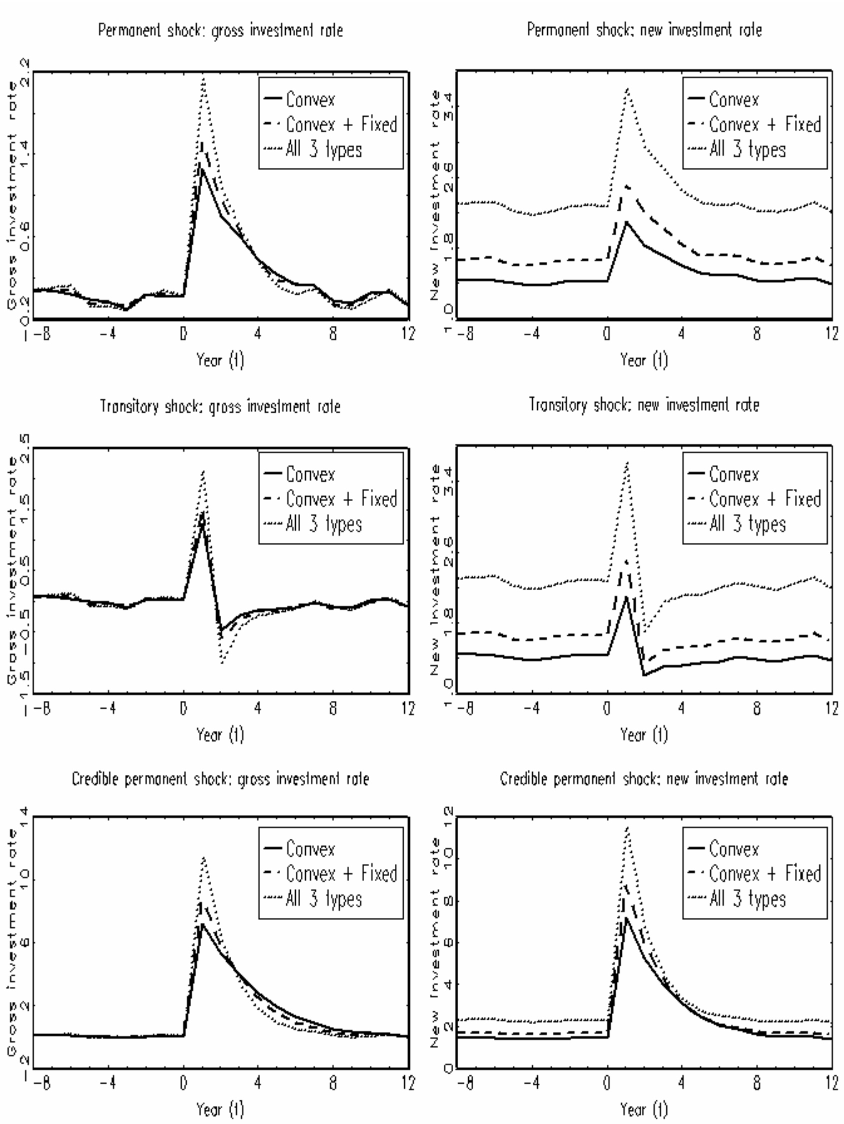
Not surprisingly, similar phenomenon can be observed in the aggregate new investment rate after a permanent profitability shock (second panel in row 1 in Figure 3). So there is an obvious difference between the firm-level and aggregate effects of non-convex adjustment costs: while fixed and irreversibility costs make investment lumpy at the firm level, *aggregate investment is more flexible if we also have fixed and irreversibility cost components*.

The second row of Figure 3 depicts the effect of the one-standard-deviation *transitory* profitability shock to the aggregate gross and new investment rates. 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 (i.e. if we allow for all 3 types of cost components). As for new investment rates, the steady-state new investment rate is again the largest when convex costs are relatively low, and one can also observe the largest response in this case.

The third experiment with a *credible permanent* profitability shock is illustrated in the third row of Figure 3. When the positive permanent profitability shock is foreseen, it enters into firms' expectations, so its effect is

[22] For the gross investment rates, figures depict deviation from the steady-state gross investment rate (δ).

Figure 3
Aggregate investment effect of various shocks

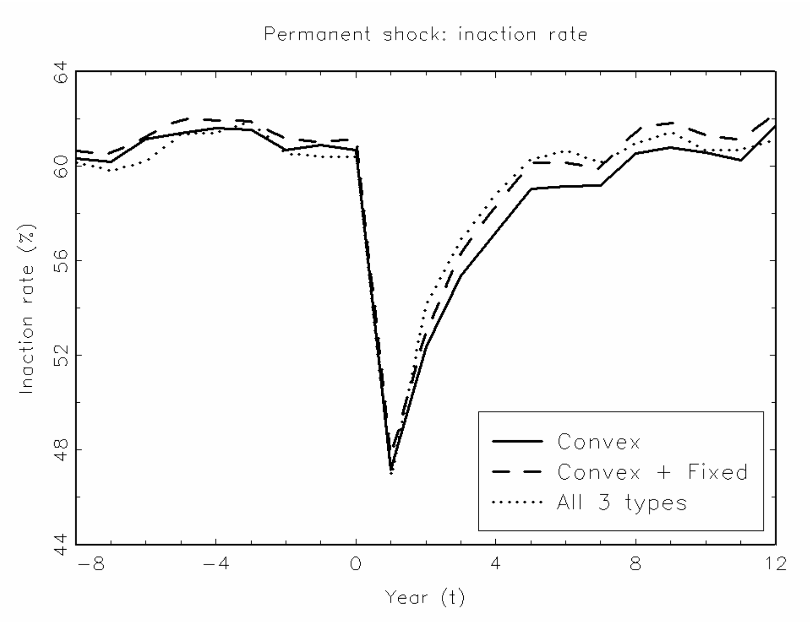


much bigger. In the first experiment we observed that if the permanent shock was a surprise shock in each period, then the immediate effect of a 1 standard deviation positive permanent shock was 1.3-2.1%, and the cumulative effect was 4-5% during the consecutive 5-6 years. Now if the permanent profitability shock is credible and it is a common knowledge that it will stay at this level forever, then its immediate effect is as high as 7.2-11.5%, while the cumulative effect is 24.1-24.3% during the consecutive 10 years. Not surprisingly if authorities can make the intended positive profitability shock foreseen and credible, then its effect can be much bigger.

Also, it is apparent (perhaps even more than before) from the graphs in the third row of Figure 3 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 the other types of profitability shocks.

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 4 illustrates the inaction rate (the proportion of firms that stay inactive) after a permanent profitability shock. As we saw in the first row of Figure 3, adjustment is quicker if we have all types of adjustment costs, as opposed to only convex costs. Now Figure 4 is telling us 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 two things. (1) If we have all types of adjustment costs, adjusting firms must make relatively larger adjustments than in case of only convex costs, and (2) firms that are inactive under 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.

Figure 4
Effect of a permanent profitability shock to the inaction rate



When tracking the inaction rates under different cost structures, one might 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 the bottom panel of Figure 5 in the Appendix, where the optimal shock-investment relationship is depicted for the case of "only convex costs". With a relatively modest convex cost parameter (in the figure $\gamma = 0.2$), the inaction rate of new investments is already visible. The case discussed here has a much higher convex cost parameter: $\gamma = 0.761$, therefore the shock-investment relationship is even 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) and Khan and Thomas (2003), who found that there is no aggregate implication of investment irreversibility at the plant level. There are two reasons for this difference. First, general equilibrium effects (through changes in equilibrium prices) are not considered here. Second, there is a difference between the magnitudes of identified profitability shocks. In this paper, the standard deviations of the aggregate and idiosyncratic profitability shocks are 0.0993 and 0.3594, respectively, much larger than the standard deviation of the productivity shock in Veracierto (2002): 0.0063.[23] As a consequence of this, the irreversibility constraint is effective for many observations in the simulations, 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 and Shapiro, 1997) find important aggregate effects of irreversible investment.

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

7 Conclusion

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:

- Non-convex adjustment costs of investment are significant, because 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 close to estimates prepared with similar methods.

On the aggregate level, the main focus is on the analysis of how aggregate profitability shocks influence aggregate investment dynamics. The **aggregate results** are the following:

- The aggregate investment equation (optimal investment rate as a function of shocks) is highly different from the firm-level investment equation (a robust result 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 the non-linear term becomes insignificant.
- Aggregate permanent profitability shocks, when they are not anticipated to be permanent, have moderate effects on aggregate investment dynamics: an aggregate shock bigger than of 10% induces an immediate response of 1-2% in aggregate gross investment rate, while the cumulative effect is not more than 4-5%.
- In contrast, credible permanent aggregate profitability shocks have much bigger effect on aggregate investment rates: a credible 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 years.
- Aggregate investment responses are larger if there are non-convexities in the investment costs, and smaller when the investment cost function is convex. This is interesting because non-convexities in the adjustment cost function make investment more lumpy at the firm-level, but make it more flexible at the aggregate level.
- If among the investment costs there are also non-convex costs, the apparently bigger adjustment takes place on the intensive margin. This is because a more flexible aggregate effect occurs at a similar inaction rate.

References

ABEL, ANDREW B. AND JANICE EBERLY (1994): “A Unified Model of Investment Under Uncertainty”, *The American Economic Review,* Vol. 84, Issue 5, December 1994, pp. 1369-1384.

BAYRAKTAR, NIHAL, PLUTARCHOS SAKELLARIS AND PHILIP VERMEULEN (2005): “Real versus Financial Frictions to Capital Investment”, *ECB Working Paper,* No. 566, December 2005.

BERTOLA, GIUSEPPE AND RICARDO J. CABALLERO (1994): “Irreversibility and Aggregate Investment”, *Review of Economic Studies* Vol. 61, Issue 2, April 1994, pp. 223-246.

CABALLERO, RICARDO J. (1992): “A Fallacy of Composition”, *The American Economic Review,* Vol. 82, No. 5, December 1992, pp. 1279-1292.

COLEMAN,WILBUR J. II. (1997): “Behavior of Interest Rates in a General Equilibrium Multisector Model with Irreversible Investment”, *Macroeconomic Dynamics,* March 1997, I(1), pp. 206-227.

COOPER, RUSSELL W. AND JOHN C. HALTIWANGER (2006): “On the Nature of Capital Adjustment Costs”*, Review of Economic Studies,* Vol. 73, No. 3, July 2006, pp. 611-633.

DARVAS, ZSOLT AND ANDRAS SIMON (2000): “Capital Stock and Economic Development in Hungary”, *The Economics of Transition,* Vol. 8, No. 1.

DOMS, MARK AND TIMOTHY DUNNE (1998): “Capital Adjustment Patterns in Manufacturing Plants”, *Review of Economic Dynamics,* Vol. 1, Issue 2, April 1998, pp. 409-429.

FAIG, MIGUEL (1997): “Investment Irreversibility in General Equilibrium: Capital Accumulation, Interest Rates, and the Risk Premium”, Mimeo, University of Toronto, 1997.

GOURIEROUX, C. AND A. MONFORT (1996): *“Simulation Based Econometric Methods”,* Oxford University Press.

MOLNÁR, LÁSZLÓ AND LÁSZLÓ SKULTÉTY (1999): “Investments in Hungary between 1992–1998” (A beruhazasok alakulasa 1992-98 között, available only in Hungarian), *Közgazdasági Szemle,* Vol. XLVI, December 1999, pp. 1041-1058.

KÁTAY, GÁBOR AND ZOLTÁN WOLF (2004): “Investment Behavior, User Cost and Monetary Policy Transmission – the Case of Hungary”, *MNB Working Papers* 2004/12.

KHAN, AUBHIK AND JULIA K. THOMAS (2003): “Nonconvex Factor Adjustment in Equilibrium Business Cycle Models: Do nonlinearities Matter?”, *Journal of Monetary Economics,* Vol. 50, 2003, pp. 331-360.

PULA, GÁBOR (2003): “Capital Stock Estimation in Hungary: A Brief Description of Methodology and Results”, *MNB Working Papers* 2003/7.

RAMEY, VALERIE A. AND MATTHEW D. SHAPIRO (1997): “Costly Capital Reallocation and the Effects of Government Spending”, *NBER Working Paper* No. 6283, November 1997.

RAMEY, VALERIE A. AND MATTHEW D. SHAPIRO (2001): “Displaced Capital: A Study of Aerospace Plant Closings”, *Journal of Political Economy,* Vol. 109, No. 5, October 2001, pp. 958-992.

REIFF, ÁDÁM (2006): “Measuring the Costs of Investment. Lessons from Firm-Level Investment Behavior”, *PhD-thesis,* Central European University 2006.

STOKEY, NANCY L. (2001): "Brownian Models in Economics Chapter 11: Investment", Lecture notes from web-page http://www.spc.uchicago.edu/users/stoke/toc.pdf.

SZANYI, MIKLÓS (1998): "Industrial investment in transition countries" (Ipari beruházások az átalakuló országokban, available only in Hungarian), *Közgazdasági Szemle,* Vol. XLV, September 1998, pp. 851-868.

VERACIERTO, MARCELO L. (2002): "Plant-Level Irreversible Investment and Equilibrium Business Cycles", *The American Economic Review,* Vol. 92, No. 1, March 2002, pp. 181-197.

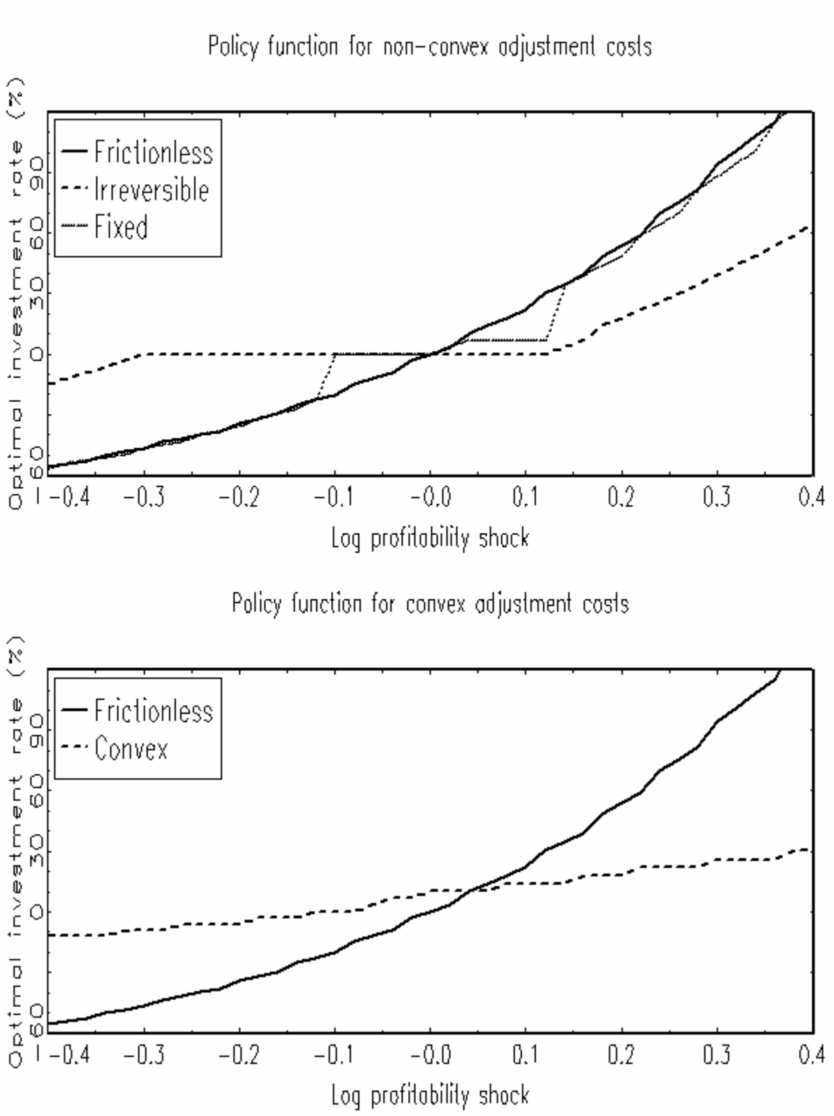
Appendix

OPTIMAL INVESTMENT UNDER DIFFERENT SIMPLE COST STRUCTURES

Figure 5 depicts the optimal investment (as a function of profitability shock) in four simple cases. The top panel compares the policy functions under non-convex adjustment costs and in the frictionless case, while the bottom panel does the same for convex adjustment costs.

1. *Frictionless* case. ($F = 0, \gamma = 0, p = 1$) Investment is non-zero whenever the shock is non-zero, i.e. we have instantaneous adjustment. Optimal investment is a convex function of profitability, reflecting 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 estimated shock-investment relationship is also slightly convex: $\widehat{\phi}_1 = 2.5233$, $\widehat{\phi}_2 = 0.4384$, $\widehat{\phi}_3 = -2.5151$. When investment is cost-free, investment rates are relatively high even for small shocks: a typical profitability shock (of one standard deviation $\widetilde{a} = 0.1$) triggers an immediate investment of 25.67% (2.5233*0.1 + 0.4384*0.1*0.1).
2. *Irreversible* case. ($F = 0, \gamma = 0, p = 0.95$) Irreversibility creates an inaction region, but the investment function remains continuous: small investment episodes are still possible. Because of the inaction region, the shock-investment relationship becomes more convex, and as it is expensive to sell capital, we need very large negative shocks (<-30%) to trigger negative investments. The estimated parameters of the reduced form regression are $\widehat{\phi}_1 = 0.8520$, $\widehat{\phi}_2 = 0.3928$, $\widehat{\phi}_3 = -0.5564$. Convexity is stronger (the relative size of $\widehat{\phi}_2/\widehat{\phi}_1$ increased), and the absolute value of the parameters decreased, so the effect of profitability shocks is much smaller (a 1 standard deviation profitability shock, $\widetilde{a} = 0.1$ leads to 8.91% = 0.8520*0.1 + 0.3928*0.1*0.1 investment rate).
3. *Fixed cost* case. ($F = 0.001, \gamma = 0, p = 1$) 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 are: $\widehat{\phi}_1 = 2.4475$, $\widehat{\phi}_2 = 0.4423$, $\widehat{\phi}_3 = -2.4165$, 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 24.92% (2.4475*0.1 + 0.4423*0.1*0.1), which is also similar to the frictionless case.
4. *Convex* case. ($F = 0, \gamma = 0.2, p = 1$) Investment is instantaneous, i.e. any shock leads to some investment activity, but as the marginal cost increased, it is of smaller magnitude (the function became flatter). Estimated reduced regression parameters: $\widehat{\phi}_1 = 0.4657$, $\widehat{\phi}_2 = 0.0672$, $\widehat{\phi}_3 = -0.2557$, so a 1 standard deviation profitability shock leads to an investment rate of 4.72% (0.4657*0.1 + 0.0672*0.1*0.1), which is much smaller than in the frictionless case.

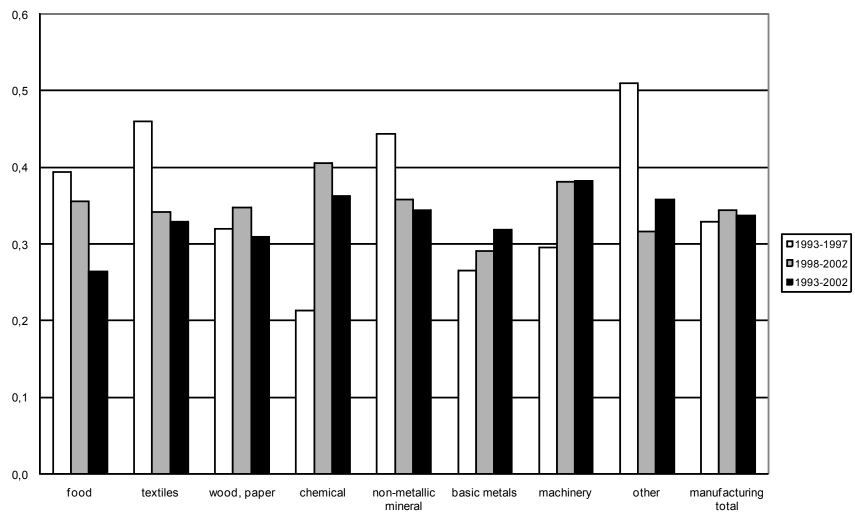
Figure 5
Optimal investment under different simple cost structures



SECTORAL ESTIMATION OF PARAMETER θ (THE CURVATURE OF THE PROFIT FUNCTION)

To further investigate the reliability of the estimated θ parameter, I estimated it separately for the different manufacturing sub-sectors (this time I only used the IV method on the shifted log-log model). As it is apparent from Figure 6, relatively more capital-intensive sectors (chemical industry, machinery) have somewhat larger estimates, which means that profit is more responsive to capital in these sectors. Figure 6 also suggests that outliers do not have large impact on the relative size of estimated industry-specific θ-s, the same result that we also found at the aggregate level.

Figure 6
Estimated θ (IV-method) by industries in different sub-periods



To investigate the stability of the estimated parameters over time, I divided the data set into two further sub-samples: one early sub-sample containing observations between 1993-1997, and another sub-sample with observations between 1998-2002. As it is apparent from Figure 6, the estimates on the whole sample (1993-2002) are mainly driven by the estimates between 1998-2002, and the estimates based in early period of 1993-97 are relatively different. This is either because relatively noise data in 1993-94 (something that Katay and Wolf (2004) also suspect), or because firms behaved somewhat differently during these early years of transition.

IDENTIFICATION: THE RESPONSIVENESS OF MATCHED MOMENTS TO STRUCTURAL COST PARAMETERS

In Section 3 I claim that the reduced-regression parameters do not contain sufficient information about F, the fixed cost of investment. The reason of this is that in the frictionless case, changing F does not lead to changes in the estimated reduced regression parameters. This is also evident on the top panel of Figure 5 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, let us investigate the following matrix:

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

This so-called "binding matrix"shows how sensitive are the matched moments to the estimated structural parameters. As Gourieroux et al. (1996) show, the variance-covariance matrix of the estimated structural parameters is proportional to $\left[B'\widehat{\Omega}B\right]^{-1}$, where $\widehat{\Omega}$ is the estimated variance-covariance matrix of the matched moments. Therefore if the reduced regression parameters are not sensitive to one of the structural parameters, i.e. if $\frac{\partial \phi_1}{\partial F}$, $\frac{\partial \phi_2}{\partial F}$ and $\frac{\partial \phi_3}{\partial F}$ are all close to zero (as in the frictionless case), then the first column of the binding matrix is also close to zero, so the estimated standard error of the fixed cost parameter is very large.

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

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

This means that a 1% increase in F would decrease ϕ_1 by $3.5E-05$, a much smaller effect than a 1% increase in γ and p would cause ($6.9E-04$ and 1.67E-04, respectively). The same is true for ϕ_2 and ϕ_3. In other words, the elements in the first column of the binding matrix are not large enough to bring down the estimated standard error of F so that it becomes significant.

In such a case the solution is to include further moments which are more responsive to changes in structural parameters. In our example these are the inaction rate and the skewness of the investment rate distribution. Adding these to the set of matched moments, the first column of the binding matrix becomes

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

(where the fourth and fifth rows of the binding matrix belong to the inaction rate and the skewness, respectively). It is clear that the main identifying moment of the fixed cost F is the inaction rate: that is the most responsive matched moment with respect to the fixed cost F.

I did similar calculations for a wide range of structural parameter vectors and always found that the inaction rate is highly responsive for the fixed cost F, while the reduced regression parameter estimates are not. So it seems to be a global phenomenon that the reduced regression alone only poorly identifies the fixed cost parameter, and it is the inaction rate that brings identification.

MNB Working Papers 2010/2
Firm-level adjustment costs and aggregate investment dynamics – Estimation on Hungarian data

Print: D-Plus
H–1037 Budapest, Csillaghegyi út 19–21.