INVESTMENT DECISIONS AND CAPITAL ADJUSTMENT COSTS: ESTIMATION OF A DYNAMIC DISCRETE CHOICE MODEL USING PANEL DATA FOR GREEK MANUFACTURING FIRMS

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Abstract

In this paper we estimate a dynamic structural model of capital investment at the firm level. Our dataset consists of a balanced panel of 1419 Greek firms. Two important features are present in our dataset. There are periods in which firms decide not to invest and periods of large investment episodes. This empirical evidence of infrequent and lumpy investment is in favour of irreversibilities and non-convex capital adjustment costs. Following Cooper and Haltiwanger (2006) we consider a dynamic discrete choice model of a general specification of adjustment costs including convex and non-convex components. We also assume total irreversibility of investment. We use an indirect inference procedure as in Gourieroux, Monfort and Renault (1993) and Smith (1993) to estimate the structural parameters. Our goal is to investigate the nature of the capital adjustment process at the firm level for Greek data.

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1. Introduction
1.1. Motivation

Investment is very important to macroeconomics. As one of the main components of aggregate demand, investment plays a central role in both the cyclical and long run performance of any economy. Economists have long been trying to understand the components of investment activity and much effort has been dedicated to this direction. Although a voluminous literature concerning investment at macro level exists, it has been in the last years when investment literature had shown an increasing concern about the modeling of investment decisions at micro level.

The neoclassical theory and Tobin’s Q theory with strictly convex adjustment costs have been the workhorse of modern investment research. The Jorgenson’s (1963) neoclassical model—with no capital adjustment costs- yielded a static decision rule for capital stock. Jorgenson’s approach compares the marginal product of capital with its \textit{user cost}. The optimal level of capital stock results from the equivalence between the marginal product of capital and the \textit{user cost} of capital. Tobin’s (1969) approach compares the capitalized value of marginal investment with the replacement cost of one unit of capital. The capitalized value of marginal investment is the market value of one unit of capital. The ratio of the market value of one unit of capital to its replacement cost is called Tobin’s \textit{q} and conditions the decision of undertaking or not an investment project.\footnote{Keynes (1936, p. 151) early noted that the incentive for creation of new capital depends on the ratio of capital market value to the cost of creating new capital.} Empirical evidence has shown the failure of these models to explain investment behavior. The estimates of investment responsiveness to fundamentals have been very low.

For analytical and econometric convenience, the literature adopted a quadratic-strictly convex function for the adjustment costs. Strictly convex adjustment costs imply that it is always optimal to make a continuous, non-zero adjustment (there are no periods of time with zero adjustment). This feature is strongly at odds with data on investment. Empirical research reveals that firms tend to concentrate the adjustment of capital in relatively short periods of time, which alternate periods of no adjustment. In other words, the adjustment process of capital can be characterized as intermittent.

\footnote{See Tobin (1969), Lucas and Prescott (1971), Mussa (1977), Hayashi (1982) and Abel (1983) for seminal contributions as well as Abel (1990) for a review and link to Jorgenson’s (1963) model.}
and lumpy. The assumption of strictly convex adjustment costs and the resulting linear dynamic models are unable to explain the infrequent and lumpy dynamic pattern of investment activity.

Doms and Dune (1998) using data for 12000 US manufacturing firms, for the period 1972-1989, find that over the half of the firms increase their capital stock more than 35 percent in a single year. Anti Nielsen and Schiantarelli (2003) report similar findings for Norwegian firms’ panel data. They note that, in every year, about 30 percent of the firms undertake no investment at all, at disaggregate level.3

The above evidence of intermittent and lumpy adjustment of capital can be supported by non-convex adjustment cost function. One way of explaining the periods of no adjustment is the inclusion of a linear (piecewise) adjustment cost to the model. Zero adjustment (inactivity) entails non-differentiability and in general, the linear adjustment cost component is interpreted as the reflection of the (partially) irreversible nature of investment. Total irreversibility means that gross investment cannot be negative. Partial irreversibility appears when the sale price of capital is lower than its replacement cost. Although linear adjustment cost explains the infrequent adjustment of capital, it cannot suitably explain the lumpiness.

To capture the lumpy character of adjustment, Hamermesh (1989) first proposed the introduction of a fixed component in the adjustment costs function. Incorporating this non-convexity, a firm decides whether to invest in capital or not. This decision depends on whether the expected gains of the investment are high enough to overcome the fixed costs. If fixed costs are substantial, firm will invest infrequently, and when it does, it will carry out a large investment.

Abel and Eberly (1994) extend the Q model incorporating quadratic, piecewise and fixed adjustment costs in their model. They show that for critical values of marginal q three potential regimes for investment occur: positive, zero and negative gross investment. In an empirical application of this model, Barnett and Sakellaris (1998) and Abel and Eberly (2002) reach the conclusion that non-linearities are important in explaining investment behavior.

Caballero, Engel and Haltiwanger (1995) and Caballero and Engel (1998, 1999) consider the gap between actual and desired capital stock to be the fundamental of investment, in order to interpret the non-linearities in the investment process. They

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3 In aggregate level this percentage goes down at 6 percent.
implement the *adjustment hazard* function. This function is defined as the difference between the log of actual and the log of desired level of capital, where the latter is the optimum level of capital obtained under zero adjustment costs. The model predicts that the larger the gap is, the higher the probability of investment to be recorded is.

Cooper and Willis (2001) criticize the “gap methodology” arguing that the results are particularly sensitive to mis-specification of the target level to which the actual capital stock is assumed to adjust.

Cooper and Haltiwanger (1993) and Cooper, Haltiwanger and Power (1999) investigate the machine replacement problem in the presence of non-convex adjustment costs. They find that, however low the level of current capital stock is (thus, the older the capital is), the higher the probability of investment to occur is. Furthermore, the longer you wait for the replacement of capital, the larger the adjustment of capital will be.

Cooper and Haltiwanger (2006), in their influential work, compare models with alternative adjustment costs: quadratic, fixed adjustment costs and adjustment costs associated with irreversibility of investment. They show that the models with only one type of adjustment cost are not successful in matching the dynamic nature of investment. On the other hand, the mixed model of non-convex and convex costs of adjustment matches satisfactorily the features of investment. In order to estimate the structural parameters of the model, Cooper and Haltiwanger use the simulated method of moments so as to match key moments of the plant level capital adjustment dynamics.4

Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005) extend Cooper and Haltiwanger’s (2006) model incorporating the existence of financial market imperfections.5

1.2. Our work

Our approach specifies a dynamic structural model of investment at the firm level in order to get a better understanding of microeconomic investment decisions and the nature of capital adjustment costs Greek firms face when they decide to undertake an investment project. The aim of this paper is to investigate the effects of

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4 See also Cooper and Ejarque (2001).
5 Lapatinas (2005) provides a detailed review of investment models and numerous references to the motivation and results of that lengthy literature.
both convex and non-convex adjustment costs of capital on Greek firms’ investment activity. Moreover its target is to look into the dynamic nature of capital adjustment process at the firm level. In addition to this, we monitor if the Greek micro data supports the presence of both convex and non-convex components of adjustment costs and more specifically to find the structural estimates of the convex and non-convex adjustment costs that are consistent with the micro evidence for the Greek economy. Our work, as far as we know, constitutes the first attempt of studying the investment behavior of Greek economy at micro level. As a result, we hope that this work not only contributes to the better understanding of the complex dynamics of investment, but it also constitutes an essential tool for the evaluation of different policies regarding Greek economy.

In this paper a dynamic structural model of capital investment at the firm level is estimated. We inquire about the investment behavior of a balanced panel of 1419 Greek firms (9933 observations) for the period 1996-2002. The evidence of infrequent and lumpy investment is present in our dataset. Based on these empirical facts, we introduce a dynamic discrete choice model with a general specification of adjustment costs including both convex and non-convex components. We also assume total irreversibility of investment. We use an indirect inference procedure as in Gourieroux, Monfort and Renault (1993) and Smith (1993), in order to estimate the structural parameters of the model.6 The structural parameters determining the magnitude of convex and non-convex adjustment costs are chosen to reproduce the econometric relationship between the investment rate and the profitability shocks with their square term. The square term of profitability shocks captures the non-linearities in the investment process.

The rest of the paper is organized as follows. In section 2 we describe the dataset used in this study. Section 3 formulates the dynamic structural model of investment. In section 4 we describe the estimation of the model: the methodology (section 4.1), the estimation method we implement (section 4.2) and the estimation results (section 4.3). Section 5 gives the main policy and modeling implications of our findings and section 6 concludes.

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6 The reason for not using analytical tools is the presence of non-convex adjustment costs that cause the dynamic problem to be discontinuous. Firms need to choose between undertaking or not an investment project.
2. Features of Actual Data

Data Set

The main data source in this paper is the ICAP firm-level database. The ICAP is the largest company providing economic data and consultative services in Greece and is a member of the international network INFOALLIANCE and participant of the European economic and business information network EUROGATE. The company is also a member of Federation of Business Information Services (FEBIS), European Association of Directory and Database Publishers (EADP), European Federation of Management Consulting Association and a member of the international research organization GALLUP INTERNATIONAL. Our data are a balanced panel of 2097 active Greek manufacturing firms over the period 1996-2002 containing 14679 observations. These are the data we get after filtering all the manufacturing firms that are registered in the ICAP databank, depending on the availability of the plant, property and equipment data. We delete firms with missing data points between 1996 and 2002. Since net profits are an essential variable to our analysis, we only keep manufacturing firms that have positive profits information. This leads to 1690 firms on 11830 observations.

The definition of capital includes plant, property, and equipment. ICAP provides fixed assets items for each firm which represent the book value of all fixed assets of the firm, including building, land and structures, machinery and equipment, intangible fixed assets and financial fixed assets such as share ownership in other companies. For this paper, the book value of the capital stock, $p_t K_t$, counts land and estates, buildings and structures, and machinery and equipments.\(^7\) Our investment measure, $p_t I_t$, is calculated by applying a perpetual inventory procedure with a depreciation of 8 percent per annum for all years\(^8\):

$$p_{t+1} K_{t+1} = p_t I_t + p_t K_t (1 - \delta_t) \Rightarrow p_t I_t = p_{t+1} K_{t+1} - p_t K_t (1 - \delta_t)$$

(1)

Real investment, $I_t$, is constructed as investment at current prices, $p_t I_t$, deflated by the investment price deflator, with 1995 to be the base year. Real capital stock, $K_t$, is

\(^7\) For more details on sample selection see the Appendix
\(^8\) This value is proposed by previous studies at micro-level, see for example Bond et al. (1999).
constructed in the same way. The investment rate is then defined as the ratio of real investment to the real capital stock, $\frac{I_t}{K_t}$.

The dataset of 1622 firms on 11354 observations is not our final dataset. Following Bayraktar, Sakellaris and Vermeulen (2005), we assume that investment rates higher than 90 percent are measuring a merger or acquisition. All the firms that display investment rate over 90 percent in any year among the period 1996-2002 are excluded from our panel. This leads to our final panel dataset of 1419 firms on 9933 observations for the period 1996-2002. The dataset is balanced and each firm has exactly 7 observations (6 observations for investment). The 1419 manufacturing firms comprise a considerable portion of the active Greek manufacturing firms. For the year 2000 the 1419 firms of our dataset represent about 6.6 percent of the private investment in Greece. They had a total investment expenditure of 1.26 billion euros, where the total private fixed investment (excluding stockbuilding) in Greece was 19 billion euros in 2000 (this is taken from the OECD data source).

![INVESTMENT RATE DISTRIBUTION](image)

Figure 1: Investment rate distribution
Summary Statistics

Table 1 shows summary statistics of the data, Table 2 shows some features of the investment rate and Figure 1 represents the distribution function of the investment rate for the period 1996-2001.

Table 1. Summary statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>median</th>
<th>std. dev</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_u/K_u$</td>
<td>0.18</td>
<td>0.14</td>
<td>0.16</td>
<td>-0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>$K_u$</td>
<td>3.8</td>
<td>0.8</td>
<td>22.4</td>
<td>0</td>
<td>719</td>
</tr>
</tbody>
</table>

Note: capital stock is in million euros measured in 1995 prices

Table 2. Features of the distribution of the investment rate

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fraction of obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>I_u/K_u</td>
</tr>
<tr>
<td>$</td>
<td>I_u/K_u</td>
</tr>
<tr>
<td>$I_u/K_u&lt;0$</td>
<td>2.5%</td>
</tr>
<tr>
<td>$I_u/K_u&gt;0.2$ (positive investment spike)</td>
<td>31.7%</td>
</tr>
<tr>
<td>$I_u/K_u&lt;-0.2$ (negative investment spike)</td>
<td>0.6%</td>
</tr>
<tr>
<td>$I_u/K_u&lt;-0.02$</td>
<td>2.02%</td>
</tr>
<tr>
<td>corr($I/K_u,(I/K)_{u-1}$)</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Note: all statistics are calculated for 1419 firms and for the period 1996-2002

All statistics are calculated by pooling data for 1419 Greek manufacturing firms and for the period of 1996-2002. In that period, the median firm had a capital stock of 0.8 million euros (in 1995 prices) and an investment rate at 0.14. The average value of the capital stock is 3.8 million euros and the average value of the investment rate is 0.18.

The statistics of the investment rate are quite close to the statistics found by Cooper and Haltiwanger (2006), Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005). The first order autocorrelation of investment rate is 0.17. It is a quite large number when it is compared to 0.058 and 0.008, which are found by Cooper and Haltiwanger and Bayraktar, Sakellaris and Vermeulen respectively, and it is about the

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9 Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2005) report a mean investment rate of around 12.2 percent, 12 percent and 19 percent respectively.
same with that found by Bayraktar. The inaction region is defined as less than 2 percent investment rate in absolute value. The fraction of observations in this region is 1.04 percent. Around 2.5 percent of the investment rates are negative (as a comparison it is 1.8 percent in Cooper and Haltiwanger, 8.68 percent in Bayraktar, and 4.7 percent in Bayraktar, Sakellaris and Vermeulen). This number is crucial as it concerns the structure of our model. The small fraction of negative investment rates comprises the basic motivation of considering investment, total irreversible—and not partial irreversible—in our model. In contrast with other studies, our formulation emphasizes the feature that a firm has only two options, of investing and not investing, and not a third one of selling capital (disinvesting). The investment rate is more than 20 percent for 31.7 percent of observations (positive investment spike). The latter number is 18.6 percent in Cooper and Haltiwanger, 17.34 percent in Bayraktar and 38 percent in Bayraktar, Sakellaris and Vermeulen. The fraction of observations that corresponds to investment rate less than -20 percent (negative investment spike) is only 0.6 percent. The presence of huge asymmetries between positive and negative investment is apparent in our dataset, since the last fraction is compared very low to the fraction of investment rate points that exceed 20 percent.

There is a huge empirical literature highlighting the importance of inaction and lumpiness in microeconomic investment datasets. Doms and Dune (1998) use data on American firms from 1972 to 1989. They find that more than half of them increase their capital stock over than 35 percent in some of the years considered. Anti Nielsen and Schiantarelli (2003), using information on Norwegian plants, find that about 30 percent of them present zero investment in an average year. Similar findings are reported concerning different countries in Barnett and Sakellaris (1998), Caballero, Engel, and Haltiwanger (1995), Abel and Eberly (2002), Eberly (1997).

The empirical evidence reported in this section stresses two important stylized facts: there are periods in which firms decide not to invest (periods of inaction) and periods of large investment episodes (lumpiness). These empirical findings clearly back up the adoption of an investment model which accounts for irreversibilities and nonconvex capital adjustment costs.
3. Model and Implications

The specifications of the model are from Cooper and Haltiwanger (2006). We assume a large and fixed number of firms. Firm $i$ begins to period $t$ with the inherited real capital stock, $K_i$, which has been adjusted in the previous period. Before making any investment decision, the firm observes the current period profitability shock. Given this state variable, the firm makes a decision on investment, depending on the nature of adjustment costs. The most general specification of the dynamic optimization problem of the firm is given by:

$$V(A_i, K_i) = \max_{\{I_t\}} \Pi(A_i, K_i) - C(I_i, K_i) - pI_i + \beta E_{A_{i+1}} V(A_{i+1}, K_{i+1})$$

subject to the following constraint:

$$I_i = K_{i+1} - (1-\delta)K_i$$

where the profit function $\Pi(A_i, K_i)$ is parameterized in the following way:

$$\Pi(A_i, K_i) = A_i K_i^{\theta}$$

where $0 < \theta < 1$, is the parameter for the curvature of the profit function. $A_i$ is the current period profitability shock that contains both an idiosyncratic component, as well as an aggregate one. It is assumed that capital is the only quasi-fixed factor of production and all variable factors have already been maximized out of the problem. $p$ is the constant cost of capital. $\delta$ is the depreciation rate of capital, which is constant too. The costs of adjustment are given by the function $C(I_i, K_i)$. $I_i$ is the level of investment that the firm’s manager chooses. The function $C(I_i, K_i)$ is general enough to have components of both convex and nonconvex costs of adjustment. The discount factor, $\beta$, is fixed and equals $(1+r)^{-1}$, where $r$ is the risk-free market interest rate.
3.1. Adjustment Cost Structures

Much attention has been given in investment literature to the adjustment costs component. As Hamermesh and Pfann (1996) mention, this component was introduced into investment models so as to provide an explanation for the observation that firms change their demand for capital more slowly than the shocks to capital demand warrant. Adjustment cost functions are not empirically observable. However, simulation results provide a better clue as to how different functional forms for adjustment costs imply different adjustment patterns. Therefore, as suggested by e.g. Cooper and Haltiwanger (2006) and Abel and Eberly (1994, 2002), attention is given to the estimation of a unified model that incorporates different types of adjustment costs. The adjustment cost functions incorporate both convex and nonconvex adjustment costs.

Convex Capital Adjustment Costs

Traditionally, a symmetric convex adjustment cost function is assumed, usually quadratic, like:

\[ C(I_{it}, K_{it}) = \gamma \left[ \frac{I_{it}}{K_{it}} \right]^2 K_{it} \]  

(5)

This is the standard specification in the literature. The parameter \( \gamma \) affects the magnitude of total and marginal adjustment costs. The higher the \( \gamma \) is, the higher the marginal cost of investing is and thus the lower the responsiveness of investment to variations in the underlying profitability of capital is. The maintenance and gradual capital adjustments can be considered as examples of convex adjustment costs. Given this adjustment cost function and the assumption of a constant factor price \( p \), the first order condition of the dynamic optimization problem (2) produces the following equality between the marginal benefit of investment and its marginal cost:

\[ \gamma I_{it} + p = \beta E_{A_{it+1}/A_{it}} V_{K_{it+1}}(A_{it+1}, K_{it+1}) \]  

(6)

\(^{10}\) Hamermesh and Pfann (1996) present a survey on different adjustment cost models.
where $V_{K_{t+1}}(A_{t+1}, K_{t+1})$ is the derivative of the value function with respect to capital. In fact, this derivative is not observable. The conditional expectation in (6) is the marginal $q$ of the Q theory. It represents the marginal value of an additional unit of future capital.\textsuperscript{11}

The convex adjustment cost function implies that the investment rate is a linear function of the fundamentals. This suggests continuous investment activity.

\textbf{Non Convex Capital Adjustment Costs and Total Irreversibility}

Convex capital adjustment costs cannot match the findings of recent empirical studies for lumpiness of investment adjustment. Firms tend to concentrate their capital adjustment into short periods of time. Consequently, firms exhibit frequent periods of no adjustment (inaction). Therefore, it has been suggested to add fixed costs and irreversibility components to the adjustment cost function. Here, we allow the case of a component of costs being fixed when investment is undertaken regardless of the investment’s magnitude. In order for this cost to be relevant at all stages of a firm’s life we assume that it is proportional to firm’s size as measured by its capital stock: $FK_{t}$. The structural parameter $F$ determines the magnitude of fixed costs. The fixed adjustment costs represent plant restructuring, worker retraining and organizational restructuring. Generally, these costs capture indivisibility in capital and increasing returns to the installation of capital. We should emphasize that when there are no fixed costs associated with capital adjustment, the value function is continuous and concave. The introduction of fixed adjustment costs breaks the concavity.\textsuperscript{12, 13}

In a model of total irreversible investment, the firm should decide on making investment or not.\textsuperscript{14} While deciding regarding this issue, the firm compares the value

\textsuperscript{11} This term is unobservable, so equation (6) cannot serve for estimation. However, Hayashi (1982) shows, that under the additional assumption of proportionality of profits to the capital stock ($\theta = 1$), the problem of marginal $q$ being unobserved can be overcome. Under the given assumptions, marginal $q$ equals average $q$ (Tobin’s $q$) which in turn can be determined –at least for publicly traded firms- from stock market information. Of course, given that the estimate of the curvature of the profit function is significantly less than 1, any Q theory is misspecified.

\textsuperscript{12} Slade (1998) and Aguirregabiria (1999) characterize the optimal decision rule for problems with nonconcave value functions.

\textsuperscript{13} The role of fixed costs was stressed by Abel and Eberly (1994, 2002), Caballero and Leahy (1996), Caballero and Engel (1999) among others.

\textsuperscript{14} Partial irreversibility allows a wedge between the selling and buying prices of capital. Total irreversibility does not allow capital to be sailed in a second-hand market. Firms cannot recover any investment cost.
function in case of capital adjustment \((V^a)\) to the value function in case of non-adjustment \((V^{na})\), and chooses the maximum:

\[
V(A_{it}, K_{it}) = \max \{V^a(A_{it}, K_{it}), V^{na}(A_{it}, K_{it})\}
\]

This formulation, occurring from the assumption of total irreversibility, emphasizes the feature that a firm has two options.\(^{15}\) The dynamic optimization problem in the case of capital adjustment is:

\[
V^a(A_{it}, K_{it}) = \max_{\{I_{it}\}} \Pi(A_{it}, K_{it}) - C(I_{it}, K_{it}) - pI_{it} + \beta E_{A_{it+1}A_0} V(A_{it+1}, K_{it+1})
\]

subject to the constraint

\[
I_{it} = K_{it+1} - (1 - \delta)K_{it}
\]

The value function in the case of no adjustment, on the other hand, is defined as follows:

\[
V^{na}(A_{it}, K_{it}) = \Pi(A_{it}, K_{it}) + \beta E_{A_{it+1}A_0} V(A_{it+1}, (1 - \delta)K_{it})
\]

In this framework, there will be periods of inaction when fundamentals are not favorable and periods of bursts of investment when fundamentals are high or low enough. The firm invests when its capital stock is less than its optimal level, otherwise prefers to avoid adjustment costs and remains inactive.

### 3.2. Value Maximization

The firm manager’s dynamic program can be written as follows:

\[
V(A_{it}, K_{it}) = \max \{V^a(A_{it}, K_{it}), V^{na}(A_{it}, K_{it})\}
\]

\(^{15}\) If we had assumed partial irreversibility, also a third alternative option of selling capital would have been occurred.
The manager needs to choose optimally between investing (adjusting capital), with value $V^a()$, or undertaking no investment at all, with value $V^{na}()$. Both of these two alternative options have a value, given by:

$$V^a(A_t, K_t) = \max_{\{I_t\}} \Pi(A_t, K_t) - \frac{\gamma}{2} \left( \frac{I_t}{K_t} \right)^2 K_t - FK_t - I_t + \beta E_{A_{t+1}/A_t} V(A_{t+1}, K_{t+1})$$

subject to the constraint $I_t = K_{t+1} - (1 - \delta)K_t$  

$$V^{na}(A_t, K_t) = \Pi(A_t, K_t) + \beta E_{A_{t+1}/A_t} V(A_{t+1}, (1 - \delta)K_t)$$ (8b)

In more detail, the value of investment given by (8a) implies that investing (buying capital) incurs two sources of costs. The first is the investment outlay, $I_t$, in which the cost of capital is normalized to one. The second is the adjustment cost, which in turn has a fixed and a convex component. The value of investment is defined as the profits minus total costs under the optimal decision, plus the discounted future value, given this period’s decision and optimal behaviour in subsequent periods. Equation (8b) gives the value of no adjustment (inaction), which of course does not involve any costs or maximization.

Due to the presence of nonconvexities, which cause discontinuity in the investment process, the model cannot be solved analytically. The model is solved using a numerical method known as the Value Function Iteration method. This method can be summarized as follows. Let $V$ be the value function. The value function iteration starts with some initial value $V_0$ and then evaluates $V_{j+1} = T(V_j)$ for $j = 0, 1, 2, \ldots$ (where $T$ is a mapping operator). The desired value function is obtained when the difference between $V_{j+1}$ and $V_j$ is less than some predetermined threshold value.\(^{16}\)

\(^{16}\) See Rust (1987a, b) for details.
The set of the structural parameters is given as \( \{ \beta, \delta, \theta, \gamma, F \} \). These together with the transition matrix for the profitability shocks determine the behavior of the model.

4. Estimation of the Model

4.1. Methodology

4.1.1. Estimation of the profit function

The profit function is given by

\[
\Pi(A_t, K_t) = AK_t^\theta
\]

where \( A_t \) is the profitability shock, \( \theta \) is the curvature of the profit function and \( K_t \) is the firm level capital stock. In this model, it is assumed that capital is the only quasi-fixed factor of production and all the variable factors have already been maximized out of the problem. We estimate \( \theta \) by regressing the natural log of net profit (net of cost of production) on the natural log of the replacement value of the capital stock using firm level Greek panel data. Although \( \theta \) is assumed to be the same for each firm at each period, we remove fixed effects in order to take into account the structural differences across firms (in order to fix the structural heterogeneity problem)\(^{17} \). If \( \theta \) is less than one, this shows the decreasing marginal profitability of capital. This might be caused by some degree of monopoly power or decreasing returns in the technology. From our data \( \theta \) is estimated as 0.7, with a standard error of 0.006. This estimate of \( \theta \) is not at variance with other estimates in the literature. Cooper and Ejarque (2001) find the same estimation in their work and a curvature of between 0.5 and 0.8 is estimated by Gilchrist and Himmelberg (1999).

4.1.2. The Fundamental of Investment: Profitability Shocks

The investment literature is traditionally relied on neoclassical Tobin’s q. Tobin’s q is equal to the ratio of the market value of firms to the replacement value of capital. The neoclassical models that take Tobin’s q as the fundamental of investment

\[^{17} \) We remove fixed effects by presenting profits and capital as deviated from the firm-level mean.\]
are too simple to explain complex dynamics of investment and rely on very strict assumptions of perfectly competitive product markets and quadratic convex adjustment costs. The quadratic convex capital adjustment costs imply a linear relationship between the investment rate and Tobin’s q, therefore neoclassical investment models deal only with the smooth part of the capital adjustment process. In recent years, this feature is strongly at odds with the empirical studies which reveal that at the micro level, firms tend to concentrate the adjustment of capital in relatively short periods of time, pointing the lumpy, infrequent and sunk nature of investment. These facts have stimulated the introduction of new empirical fundamentals in order to explain investment behaviour.

Caballero and Engel (1999) introduce the gap between the desired and actual capital stock, which, until today, is the most commonly used fundamental of investment in the studies. In their model, once the gap reaches a threshold level, the adjustment process starts at once. The empirical investigation of this fundamental by Caballero, Engel and Haltiwanger (1995) shows that the response of investment to the gap is nonlinear, supporting therefore the existence of non convex adjustment costs. In parallel with the development of the literature arguing that non convexities and irreversibilities play a central role in investment, a literature relating the empirical failure of the neoclassical model to possible measurement errors in Tobin’s q evolved. This literature focuses on correcting possible mismeasurement of Tobin’s q in order to explain the inadequate results of the “traditional” literature. The idea behind is that the presence of measurement errors prompts fundamentals to be insufficient determinants of investment. Since the main indicator of firms’ investment opportunities is expected profitability and since it is not easy to be directly calculated, it is generally approximated by current profitability measures. Abel and Blanchard (1986) first proposed present value of marginal revenue flows of capital to be one of these measures and Gilchrist and Himmelberg (1995, 1999) constructed this “Fundamental Q” measure pooling U.S firm level data. The last and most recently worked up alternative fundamental of investment is profitability shocks. Profitability

---

19 Hayashi (1982) and Abel (1979) show that the neoclassical model with convex adjustment costs yields the marginal q value. Since marginal q is unobservable to the econometrician, marginal q can be approximated by the average value of q, under the strict assumptions of linear homogeneous net revenue function and perfectly competitive markets. The use of average q as a proxy measure of marginal q might be subject to measurement errors.
shocks are defined as changes in firms’ profits that cannot be attributed to changes in their factors of production.

4.1.3. Calculation of the profit shocks

There are two alternative ways of calculating the profitability shocks, $A_t$. The first way calculates $A_t$ indirectly through the first order condition for profit maximization with respect to employment. The second way of calculating $A_t$ is through regressing profits on capital, and taking the residuals. Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2006) use the first way because the standard deviation of the shocks using this way is low compared to the standard deviation calculated using the second way. Low standard deviation of the shocks causes the transition matrix to be more informative. Although we fully appreciate the fact that using profit data instead of employment data might raise measurement errors, since employment data is not available we compromise on the second way. We regress the log of profits on the log of capital including time dummies, after removing the fixed effects, and the residuals of this regression represent the idiosyncratic profitability shocks, $a_t$ ($i$ denotes the firm and $t$ the period)\(^{20}\). Table 3 shows some features of the idiosyncratic profitability shocks.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-0.72</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.34</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.1</td>
</tr>
<tr>
<td>Autocorrelation</td>
<td>0.693</td>
</tr>
</tbody>
</table>

4.1.4. The relationship between investment and profitability shocks

Throughout this paper we study the following relationship between investment and profitability shocks

$$\tilde{i}_t = \Psi_0 + \Psi_1 a_t + \Psi_2 (a_0)^2 + u_t$$

\(^{20}\) Since we remove fixed effects, include time dummies, and the variables are taken in log form, the residual shocks are the firm specific idiosyncratic shocks in log form (time dummies capture the aggregate component of the profitability shocks).
where \( \tilde{i}_{it} \) is the deviation of the investment rate of firm \( i \) in period \( t \) from the firm specific mean, \( a_{it} \) is the idiosyncratic profitability shock, \( (a_{it})^2 \) is the square term of \( a_{it} \). The square term is included in order to test for our dataset the argument that the investment process is a non-linear function of the fundamentals.

| Table 4. Summary Statistics of the regression variables |
|---------------------------------|---------|------|------|-----|
| \( \tilde{i}_{it} \)             | 0.00    | 0.154| -1.07| 0.7 |
| \( a_{it} \)                    | 0.00    | 0.1   | -0.72| 0.34|
| \( (a_{it})^2 \)                | 0.01    | 0.02  | 0.00 | 0.52|

| Table 5. Correlation matrix of the regression variables |
|--------------------------------|-------|------|------|------|
| \( \tilde{i}_{it} \)         | 1     |      |      |      |
| \( a_{it} \)                  | 0.187 | 1    |      |      |
| \( (a_{it})^2 \)              | -0.016| -0.376| 1    |      |

<p>| Table 6. Actual Data: Regression Results |
|------------------------------------------|-------|------|</p>
<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Estimated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_{it} )</td>
<td>0.322* (0.017)</td>
</tr>
<tr>
<td>( (a_{it})^2 )</td>
<td>0.443* (0.08)</td>
</tr>
</tbody>
</table>

* significant at the 1 percent level. Rsquared adjusted = 0.04

Note: data was pooled for 1419 Greek firms and for the period 1996-2002. The estimation technique is the least square. The dependent variable is the deviation of the investment rate from the firm specific mean. Standard errors are reported in the parentheses.
Table 4 shows some summary statistics of the regression variables. Table 5 gives the correlation matrix of the regression variables. Notice that the investment rate is positively correlated with the contemporaneous profitability shock (correlation = 0.187). The least square estimated coefficients are reported in Table 6. The regression results show that both the level and the square term of the profitability shocks are important in explaining investment. Thus, we could say that these results support the argument of non-linear response of investment to its fundamentals.

4.1.5. Simulations

The coefficients $\{\beta, \delta, \theta\}$ and the profitability shocks are calibrated using the ICAP Greek firm-level database. We fix the discount factor $\beta$ at the empirically reasonable value 0.97.$^{21}$ We have also estimated the model with different values of $\beta$ (0.95 and 0.99) obtaining similar results. Following the relevant micro-level studies we pin down the depreciation rate, $\delta$, at 0.08. The curvature of the profit function, $\theta$, is estimated as 0.7 by regressing the log of profit on the log of capital using Greek firm-level data.

The profitability shocks, $A_t$, contain both an aggregate and an idiosyncratic component. The aggregate shocks are assumed to have a high and low value: $\{0.9, 1.1\}$. The serial correlation between the aggregate shocks is calculated as 0.8. We represent the aggregate shock process as a two-state Markov process with a symmetric transition matrix in which the probability of remaining in either of the two aggregate states is 0.8. The details of calculating the idiosyncratic shocks, $a_t$, are in section 4.1.3. We assume that the idiosyncratic profitability shocks follow an AR(1) process:

$$ a_{t+1} = \rho a_t + \varepsilon_{t+1} \quad \text{where} \quad \varepsilon_t \overset{iid}{\sim} N(0, \sigma^2) $$

(9)

We approximate this process by a discrete Markov process using the method outlined in Tauchen (1986). A time invariant Markov chain is defined by $(Z, T)$, where $Z \in \mathbb{R}^r$ is a vector describing the states possible of the Markov process, and $T$ is an

$^{21}$ is set approximately at 3 percent which is the average real interest rate on government bonds in Greece
$n \times n$ dimensional transition matrix with elements $(i, j)$ that express the probability of
transition from state $Z_i$ to state $Z_j$. Thus, the rows of $T$ sum to unity. The method
proposed by Tauchen (1986) is used to create a discrete state space representation of
the stochastic AR(1) process for the firm specific shocks. The idiosyncratic shocks take 11 different values. The serial correlation of the idiosyncratic shocks is 0.69. The
standard deviation is 0.1. Table 7 presents the idiosyncratic shocks and the transition
matrix of these shocks.

Table 7. Idiosyncratic shocks and their transition matrix

<table>
<thead>
<tr>
<th>idiosyncratic shocks</th>
<th>-0.1815</th>
<th>-0.1114</th>
<th>-0.0757</th>
<th>-0.0478</th>
<th>-0.0232</th>
<th>0</th>
<th>0.0233</th>
<th>0.0478</th>
<th>0.0757</th>
<th>0.1115</th>
<th>0.1815</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1815</td>
<td>0.4478</td>
<td>0.2159</td>
<td>0.1303</td>
<td>0.0824</td>
<td>0.0524</td>
<td>0.0328</td>
<td>0.0197</td>
<td>0.0111</td>
<td>0.0054</td>
<td>0.002</td>
<td>0.0003</td>
<td>1</td>
</tr>
<tr>
<td>-0.1114</td>
<td>0.2159</td>
<td>0.2046</td>
<td>0.1652</td>
<td>0.1291</td>
<td>0.0983</td>
<td>0.0724</td>
<td>0.0509</td>
<td>0.0333</td>
<td>0.0194</td>
<td>0.0089</td>
<td>0.002</td>
<td>1</td>
</tr>
<tr>
<td>-0.0757</td>
<td>0.1303</td>
<td>0.1652</td>
<td>0.1571</td>
<td>0.1396</td>
<td>0.1188</td>
<td>0.0971</td>
<td>0.0757</td>
<td>0.0553</td>
<td>0.0363</td>
<td>0.0194</td>
<td>0.0054</td>
<td>1</td>
</tr>
<tr>
<td>-0.0478</td>
<td>0.0824</td>
<td>0.1291</td>
<td>0.1396</td>
<td>0.137</td>
<td>0.1273</td>
<td>0.1131</td>
<td>0.0957</td>
<td>0.0762</td>
<td>0.0553</td>
<td>0.0333</td>
<td>0.011</td>
<td>1</td>
</tr>
<tr>
<td>-0.0232</td>
<td>0.0524</td>
<td>0.0983</td>
<td>0.1188</td>
<td>0.1273</td>
<td>0.1278</td>
<td>0.1211</td>
<td>0.1113</td>
<td>0.0957</td>
<td>0.0757</td>
<td>0.0509</td>
<td>0.0197</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0.0328</td>
<td>0.0724</td>
<td>0.0971</td>
<td>0.1131</td>
<td>0.1221</td>
<td>0.1254</td>
<td>0.1221</td>
<td>0.1131</td>
<td>0.0971</td>
<td>0.0724</td>
<td>0.0328</td>
<td>1</td>
</tr>
<tr>
<td>0.0233</td>
<td>0.0197</td>
<td>0.0509</td>
<td>0.0757</td>
<td>0.0957</td>
<td>0.1113</td>
<td>0.1221</td>
<td>0.1278</td>
<td>0.1273</td>
<td>0.1189</td>
<td>0.0983</td>
<td>0.0524</td>
<td>1</td>
</tr>
<tr>
<td>0.0478</td>
<td>0.0111</td>
<td>0.0333</td>
<td>0.0553</td>
<td>0.0762</td>
<td>0.0957</td>
<td>0.1131</td>
<td>0.1273</td>
<td>0.137</td>
<td>0.1396</td>
<td>0.1291</td>
<td>0.0824</td>
<td>1</td>
</tr>
<tr>
<td>0.0757</td>
<td>0.0054</td>
<td>0.0194</td>
<td>0.0363</td>
<td>0.0553</td>
<td>0.0757</td>
<td>0.0971</td>
<td>0.1188</td>
<td>0.1396</td>
<td>0.1571</td>
<td>0.1652</td>
<td>0.1303</td>
<td>1</td>
</tr>
<tr>
<td>0.1115</td>
<td>0.002</td>
<td>0.0080</td>
<td>0.0194</td>
<td>0.0333</td>
<td>0.0509</td>
<td>0.0724</td>
<td>0.0983</td>
<td>0.1291</td>
<td>0.1652</td>
<td>0.2046</td>
<td>0.2159</td>
<td>1</td>
</tr>
<tr>
<td>0.1815</td>
<td>0.0003</td>
<td>0.002</td>
<td>0.0054</td>
<td>0.011</td>
<td>0.0197</td>
<td>0.0328</td>
<td>0.0524</td>
<td>0.0824</td>
<td>0.1303</td>
<td>0.2159</td>
<td>0.4478</td>
<td>1</td>
</tr>
</tbody>
</table>

The transition matrix for the idiosyncratic shocks is computed from the empirical
transitions observed at the firm-level and reproduces statistics from the idiosyncratic
profitability shock series.

4.2. Estimation Method: Indirect Inference

The vector of remaining structural parameters to be estimated is $\Theta \equiv (\gamma, F)$.
The approach is to estimate these parameters by matching the implications of the
structural model with key features of the data. The methodology that is used for this
purpose is the structural empirical approach called indirect inference method. This
method is explained by Gourieroux et al. (1993), Smith (1993), Gourieroux and
Monfort (1996) and works as follows.

With an arbitrary set of parameter values and by using the Value Function
Iteration method we solve the firm’s dynamic programming problem. After the
model is solved for given $\Theta$ values, a 500 firms and 100 periods simulated panel data

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22 For some theory, see Ljungqvist and Sargent (2000, Chapter 1), Stokey and Lucas (1989, Chapters 8,
11 and 12) and Adda and Cooper (2003).
23 See section 3.2.
are obtained using the created policy functions. This simulated data set is used to calculate the model analogues of the coefficients and/or moments we obtained using actual data. The reduced form equation we estimate using both the simulated and actual data is

\[
\tilde{i}_i = \Psi_0 + \Psi_1 a_i + \Psi_2 (a_i)^2 + u_i
\]

where \( \tilde{i}_i \) is the deviation of the investment rate of firm \( i \) in period \( t \) from the firm specific mean, \( a_i \) is the idiosyncratic profitability shock, \((a_i)^2\) is the square term of \( a_i \). The square term is included in order to take into account the non-convexities in the adjustment process. Denoting as \( \Psi^d \) the vector of moments from the actual data and as \( \Psi^s(\Theta) \) the vector of moments from data simulated given \( \Theta \), the indirect inference routine looks for the structural parameter estimates that minimize the weighted distance between the two vector of moments. We try to minimize with respect to \( \Theta \) in order to find the structural parameter values is the following quadratic function: \[J(\Theta) = (\Psi^d - \Psi^s(\Theta))^TW(\Psi^d - \Psi^s(\Theta))\]

where \( W \) is a weighting matrix. The vector of true moments is \( \Psi^d = [\Psi_1, \Psi_2] = [0.322, 0.443] \). Given the discontinuities in the model and the discretization of the state space, as it is the case in related studies, we use the method of simulated annealing in order to minimize \( J(\Theta) \) with respect to \( \Theta \). As Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2006) notice, simulated annealing is the ideal algorithm for dealing with complex functions, first because it explores the function’s entire surface and can escape from local optima by moving uphill and downhill and second, because the assumptions required with respect to functional forms are quite relaxed.

---

\[24\] As pointed by Gourieroux and Monfort (1996), minimizing the distance between the simulated data moments and the actual data moments will emerge consistent estimates of the structural parameters.

\[25\] We implement the 2x2 identity matrix.
4.3. Estimation Results

Using the indirect inference method, the structural parameters of the model proposed in section 3 are estimated. Table 8 gives the estimated values.

Table 8. Estimated Structural Parameters

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Estimated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>0.5164 (0.0130)</td>
</tr>
<tr>
<td>$F$</td>
<td>0.1557 (0.0035)</td>
</tr>
</tbody>
</table>

Note: standard errors are reported in parentheses

The structural parameters $\gamma$ and $F$ are significantly different from zero, indicating the importance of convex and fixed adjustment costs. It is essential to bring to reader’s notice that the estimation results are affected by the fact that we are only exploiting the binary choice between zero investment and positive investment. In this sense, our results are not directly comparable with the results obtained by Cooper and Haltiwanger (2006), Bayraktar (2002), and Bayraktar, Sakellaris and Vermeulen (2006).

The estimated value of the coefficient determining the magnitude of the convex adjustment cost, $\gamma$, is 0.5164. The estimated value of the coefficient determining the magnitude of the fixed adjustment cost, $F$, is 0.1557. This implies that a firm that undertakes an investment project faces a fixed adjustment cost of 15.57 percent of installed capital. The estimated value of the coefficient $F$ is high compared to the estimates found by relevant studies.

Now we focus on the comparison of the simulated data results with the actual data results. Table 9 shows the regression coefficients of the reduced form regression of investment rate on the profitability shocks using the actual data and the simulated data.

26 Cooper and Haltiwanger (2006) estimate $\gamma$ as 0.455, Bayraktar (2002) finds an estimated $\gamma$ at 0.311 and Bayraktar, Sakellaris and Vermeulen (2005) estimate $\gamma$ as 0.532.

27 Cooper and Haltiwanger (2006), Bayraktar (2002), Bayraktar, Sakellaris and Vermeulen (2005) estimate $F$ at 0.069, 0.029 and 0.031 respectively.

28 The simulated data regression coefficients were obtained using the simulated data that were generated using the estimated values of Table 8.
Table 9. Actual Data versus Simulated Data: Regression Results

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Actual Data</th>
<th>Simulated Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_n$</td>
<td>0.322</td>
<td>0.322</td>
</tr>
<tr>
<td>$(a_n)^2$</td>
<td>0.443</td>
<td>0.443</td>
</tr>
</tbody>
</table>

*Note: The estimation technique is the least square. The dependent variable is the deviation of the investment rate from the firm specific mean.*

Table 10. Moments of actual data versus moments of simulated data

<table>
<thead>
<tr>
<th>Moments</th>
<th>Actual Data</th>
<th>Simulated Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean of investment rate</td>
<td>0.18</td>
<td>0.10</td>
</tr>
<tr>
<td>correlation ($\tilde{I}_n, a_n$)</td>
<td>0.187</td>
<td>0.39</td>
</tr>
<tr>
<td>autocorrelation of inv. rate</td>
<td>0.17</td>
<td>-0.03</td>
</tr>
<tr>
<td>investment rate (&gt; 0.2)</td>
<td>31.7%</td>
<td>13.8%</td>
</tr>
<tr>
<td>investment rate &lt; 0</td>
<td>2.5%</td>
<td>16.9%</td>
</tr>
</tbody>
</table>

The estimated coefficients using the actual and simulated data are exactly the same. In Table 10 we also compare some moments of actual data and simulated data. The dynamics of the simulated data seems to be different than the dynamics of the actual data. The weakest result produced by the model compared to the actual results is the autocorrelation of the investment rate. While the actual value is 0.17, it is estimated as -0.03 by the model. One possible explanation for such a low estimated value might be related to the presence of financial frictions. The model is not working well in terms of the estimated autocorrelation of the investment rate due to the omission of financial market imperfections. Furthermore, it is possible that measurement error in the profit data is the cause of some of the difference in dynamics. Despite this, the overall investment rate is captured quite well by the model. The actual value of the average investment rate is 0.18 and it is estimated as 0.1 by the model. With regard to the contemporaneous correlation of the investment rate with the profitability shocks, while the correlation in the actual data is 0.19, we have a comparable estimation of 0.39. Now, with regard to the fraction of the observations corresponding to the different values of the investment rate, we think
that the nonlinear effect of the profitability shocks is not perfectly captured as evidenced by a somewhat different fraction of firms having investment bursts. In parallel, the fraction of observations with a negative investment rate is estimated as 16.9 percent, while its actual value is 2.5 percent.

5. Why adjustment costs are important – Policy and modeling implications

Firm’s changes in input demands are liable to adjustment costs and economists are concerned of what those costs look like. This is for a wide range of reasons, many having to do with the ability to predict the effects of factor market policies at external shocks and furthermore, aggregate investment sums firms’ changes in their capital stock and measures responses that are determined by the structure and size of the adjustment costs. Therefore, GDP is partly determined by adjustment costs, as are labor productivity and total factor productivity. In addition, knowledge of structures of adjustment costs is crucial for predicting the possibly long and complex path of responses of capital demand to shocks, therefore should be a basic input into debates over the long run effects of policies that concern investment.

Specifically, to predict the effects of proposed policies or the possible impact of external shocks, we need to know (as Hamermesh and Pfann (1996) mention): 1) the source of the adjustment cost the firm is facing. Is it adjustment costs that generate slow adjustment, or does stickiness arise from other aspects of a firm’s behavior or market environment? 2) The structure of these costs. Without knowing the structure of the costs, the path of firm’s capital demand in response to shocks cannot be predicted, and 3) the size of adjustment costs. Higher costs associated with investment reduce the firms’ long-run demand for capital.

Elaborating these questions, we have found that slow adjustment is generated – and can be explained – by costs associated with changing capital demand. Adjustment costs are found to be statistically important, thus firms change their demand for capital more slowly than the shocks to capital demand warrant, due to the interference of these costs\textsuperscript{29}. As far as the structure of the costs is concerned, the estimation results reported in Tables 8 and 10 indicate that a model which mixes both convex and non-

\textsuperscript{29} Precisely speaking, we assume and verify that the reason for slow adjustment (once expectations about shocks are accounted for) is the costs associated with altering the demand for capital.
convex adjustment processes can match the moments calculated from firm-level data quite well. The conclusion that adjustment costs are not characterized by a symmetric quadratic structure (as is usually assumed) affects aggregate behavior.

Finally, with regard to the size of the adjustment costs, our findings indicate high costs associated with investment in the Greek (micro) economy. The estimated value of the coefficient determining the magnitude of the convex adjustment costs ($\gamma$) is found to be 0.5164, which is higher than the values structurally estimated by other authors for other countries. Cooper and Ejarque (2001) estimate $\gamma$ to be 0.149 in their study for USA. Cooper and Haltiwanger (2006), Bayraktar (2002) and Bayraktar, Sakellaris and Vermeulen (2005) estimate the value of $\gamma$ to be very close to the value found here (namely, 0.5164) (see footnote 26 for details). The estimated value of the coefficient determining the magnitude of the fixed adjustment has been found to be high (higher than in most of the literature) (see footnote 27 for details). A Greek firm that undertakes an investment project faces a fixed adjustment cost of 15.57 percent of installed capital. The variation of our results compared to other studies most likely arises from differences in specification, as is discussed in section 4.3 (see p.22).

With respect to economic modeling, Wilcoxen (1993, p.96) in a previous article in this journal argues that it is important to understand the nature of adjustment costs because it determines the medium- and long-run supply elasticity: “…since the elasticity is sensitive to even small departures of the adjustment cost parameter from unity, it is clearly inappropriate to assume adjustments costs are zero without considerable empirical evidence. This suggests that a fruitful area for future research is the empirical determination of adjustment cost parameters at the industry level. In addition, such research would help identify the underlying source of adjustment costs and would indicate whether these costs would be influenced by policy”. Goyal (1994), also in this journal, takes a step ahead and argues that it is important to know the structure of adjustment costs because it determines the long-run elasticity, which is

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30 This parameter is investigated in many empirical studies. In general, the estimated value of this parameter is much higher in the literature (not structural estimation like this one). Hayashi (1982) estimates $\gamma$ as 20. Gilchrist and Himmelberg (1995) find the value as 3. The thing is—as pointed out by Cooper and Haltiwanger (2006)—that these empirical results may not be accurate due to the presence of the measurement errors in Tobin’s q. It is assumed that the marginal q is equal to the average q, hence it is possible that a measurement problem exists in calculating empirical q and this produces extremely high $\gamma$. 
one of the most vexed questions in satisfactory modeling of dynamic Applied General Equilibrium Models.

Regarding policy issues, recent discussions stress that firm-specific aspects are not the unique determinants of capital adjustment. Government’s fiscal activity is also important. Public policy plays an important role in the firm’s capital investment decision and the cognizance of adjustment cost’s source, structure and size has been shown to have a significant bearing on the effectiveness of fiscal policy. Turnovsky (1996), for example, picks up the argument that firm-specific aspects are not the unique determinants of capital adjustment and develops a one-sector endogenous growth model in which capital investment incurs adjustment costs that are related to governmental activity. He shows that the presence of adjustment costs causes a reduction in the equilibrium growth rate. In addition, he demonstrates that adjustment costs reduce the effects of capital taxes on the equilibrium growth rate and cause an expansion in productive government expenditure$^{31,32}$.

Closing this section it should be noted that the results we obtain here will allow us to improve the predictions of the paths of aggregate investment based on the knowledge of the dispersion of underlying shocks. Furthermore, knowing that costs are not always symmetric and convex guides us to a better understanding of the likely impacts of changes in capital-market policies than we obtain if we rely on the standard assumption. Last, but not least, this paper gives incipient clues and hints of how (stochastic) aggregation maps microeconomic behavior into macroeconomic relations.

6. Conclusions

In this paper a dynamic model of investment for Greek manufacturing firms is estimated. A balanced panel dataset of 1419 firms on 9933 observations for the period 1996-2002 has pointed strong evidence of inaction and lumpy investment. On account of these empirical observations, and since descriptive statistics should be taken as a “guide”, we have adopted a model that takes into consideration total irreversibility of

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$^{31}$ See also Ott and Soretz (2006) who extend the work of Turnovsky (1996) by assuming that adjustment costs are a function of governmental activity.

$^{32}$ The introduction of the governmental activity into the adjustment cost function can be an interesting extension.
investment and includes not only convex but also non convex adjustment costs. The adjustment cost function we assumed included both quadratic and fixed components.

We have estimated the structural parameters of the model using the indirect inference method. The indirect inference procedure works as follows. First, we solve the firm’s dynamic programming problem for arbitrary values of the structural parameters and generate the corresponding optimal policy functions. Second, we use these policy functions and arbitrary initial conditions to generate simulated data. Third, this simulated data set is used to calculate the analogues coefficients obtained from the regression of the actual data. Finally, using the simulated annealing algorithm we estimate the structural parameters.

The results indicated that the structural model suits the data adequately. The structural parameters $\gamma$ and $F$ are significantly different from zero, indicating the importance of both convex and fixed adjustment costs. This rejects the neoclassical model with convex adjustment costs only and buttresses up the argument that adjustment costs are more complex than we once thought. Our estimates imply that frictions are important in determining firm’s investment dynamics: traditional representative agent models with convex costs of adjustment only seem to be incapable of capturing the dynamics of investment and capital accumulation.

One of the gains to structural estimation presented in the present paper is to use the estimated parameters for policy analysis. Our next work will be the evaluation of the estimated model in terms of its predictions of the (dis)aggregate effects of an investment tax credit.

An issue that we plan to explore further is whether the presence of non-convexities at microeconomic level matters for aggregate investment. Whether, for example, the aggregation of individual agents facing non convex (lumpy) adjustment costs generates differences in the paths of aggregate investment to external shocks and whether linearity in the underlying adjustment cost structure determines the paths of business cycles. This issue of aggregate implications has already drawn considerable attention in the literature. Caballero, Engel and Haltiwanger (1995) find that introducing the nonlinearities created by non-convex adjustment processes can improve the fit of aggregate investment models for sample periods with large shocks. Cooper, Haltiwanger and Power (1999) find that there are years where the interaction
of an upward sloping hazard and the cross sectional distribution of capital vintages matters in accounting for aggregate investment.

Whereas the analysis has taken labour as flexible factor of production and already being maximized out of the problem, the adjustment cost function could be augmented to include interactions between labour and capital inputs. In future, our study will gravitate to this interesting topic too.
Data Appendix

Sample Selection

The source of the data set used in this paper is the ICAP databank, which is a database providing financial, statistical and market information for the publicly traded companies in Greece. The data set covers, not only the big manufacturing firms, but almost all the Greek manufacturing sector. For our analysis we pooled all the active Greek manufacturing firms that ICAP database had available information for the period 1996-2002. The elimination of firms is conducted following a number of steps:

1. We filter the data depending on the availability of the plant, property and equipment data points. We delete firms with missing data points for the book value of capital stock on plant, property and equipment. The total number of firms after this elimination is 2097. These firms comprise a balanced panel of 14679 observations over the period 1996-2002.

2. We only keep firms if they have profits information. This leads to 1690 firms on 11830 observations.

3. We do not accept this as our final dataset. We need to delete the firms which have involved in significant acquisitions or mergers. There are different ways to eliminate these firms. Bayraktar (2002) adopts the method that Gilchrist and Himmelberg (1995) propose and excludes the firms whenever

\[ |G_t - G_{t-1} - I_t + R_t| > 0.15G_{t-1} \]

where \( G_t \) is the book value of the capital stock, \( I_t \) is nominal capital expenditure and \( R_t \) is the retirement of capital. We do not use this formula.

Following Bayraktar, Sakellaris and Vermeulen (2005), practically we assume that investment rates higher than 90 percent are measuring a merger or acquisition. We exclude from our panel all the firms that display investment rate over 90 percent in any year among the period 1996-2002. This leads to our final balanced panel dataset of 1419 firms on 9933 observations for the period 1996-2002. Every firm has exactly 7 observations (6 observations for investment).
Description of the Variables

Raw variables from the ICAP CD-rom:

LAND AND ESTATES
BUILDINGS AND STRUCTURES
MACHINERY AND EQUIPMENT
NET PROFITS: the nominal book value of net profits (net of cost of production).

Constructed variables

Book value capital stock, $p_tK_t$: the book value of the capital stock was constructed by the calculation \( \text{LAND AND ESTATES} + \text{BUILDINGS AND STRUCTURES} + \text{MACHINERY AND EQUIPMENT} + \text{INTANGIBLE FIXED ASSETS} \)

Investment at current prices, $p_tI_t$: since gross investment is not directly available from ICAP database, it has to be constructed using depreciation and capital stock observations. We use the accounting identity \( p_tI_t = p_{t+1}K_{t+1} - p_tK_t(1-\delta) \).

Investment price deflator: was taken from OECD data source (“deflator for total investment”), (based year 1995)

Real investment, $I_t$: is constructed as investment at current prices deflated by the investment price deflator.

Real capital stock, $K_t$: constructed as book value capital stock deflated by the investment price deflator.

Investment rate, \( \left( \frac{I}{K} \right)_t \).

Greek GDP deflator: was taken from OECD data source (based year 1995)

Real net profits: constructed as net profits deflated by the Greek GDP deflator.
References


