NON-LINEAR RESPONSE OF FIRM INVESTMENT TO Q: EVIDENCE FROM GREEK LISTED FIRMS

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Abstract

A dynamic-panel model is applied in order to empirically investigate the relationship between business fixed investment and Tobin's *q* for the firms listed in the Athens Stock Exchange (ASE). In particular, we search for non-linearities in the underlying relationship between investment and fundamentals, consistent with the presence of multiple regimes. The empirical results support a discontinuity identifying two-regimes: (a) wherein the first (for values of *q* below a certain threshold) investment is inelastic to *q*, while in the second it exhibits a positive relationship, and b) a further non-linearity expressed in a concavity of the investment- *q* relationship implying that for the segment where investment reacts to fundamentals positively, it does so at a decreasing rate evidence which is consistent with the presence of non-convexities in adjustment costs.

Keywords: Investment, Non-linearities, Panel Data, Tobin's q

1. INTRODUCTION

Investment can be considered as one of the main components of aggregate demand since it plays a central role in both the cyclical and long-run performance of any economy. Economists were always keen to understand investment activity, especially at the macro level. There is a voluminous literature concerning investment at the macro level, however not as much at the micro level, but only recently there is an increasing concern about the modelling of investment decisions at the firm level. Most of the econometric models of investment applied to firm-level data in many empirical studies may be viewed as special cases of a general factor demand model. In most of these studies capital input is assumed to be homogeneous and treated as the only quasi-fixed factor used by the firm.

The most popular of these models has been the *q* model, developed by Tobin (1969). The intuition behind Tobin's *q* model is that absent considerations of taxes or capital market imperfections, a value-maximizing firm will invest as long as the shadow value of an additional unit of capital (marginal *q*) exceeds unity. Tobin's suggestion was that a firm's investment decision should be related to the market value of the firm's capital compared to its replacement cost. Under the assumptions of constant returns to scale, strictly convex costs of adjusting the capital stock and investment reversibility, it is ensured that investment is a linear function of fundamentals (Mussa, 1977; Abel, 1983).

On this note, Hayashi's (1982) proof that average Q, which is observable, is equal to the inherently unobservable marginal q when profits are linear in capital and financing is frictionless. However, recent developments in investment research stress, differently from the traditional literature, the possibility of non-convex adjustment cost and consequently a non-linear relationship between investment and its determinants. Irreversibilities and other forms of non-convexities may explain why the traditional models of investment do not perform well (e.g. Cooper and Haltiwanger, 2006[1]; Bloom, 2007 etc.) The feature of strictly convex adjustment costs is strongly at odds with actual 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 and lumpy (Lapatinas, 2007).

[1]In a similar note, Lapatinas (2009.2012) provides an analogous study with the difference that the quasi-fixed factor of production is now labour.

In particular, Arrow (1968) studied irreversibility of investment as an extreme case of kinked, linear adjustment costs. More recently, Abel and Eberly (1994) introduced the fixed cost of capital and irreversibility into the traditional adjustment function, showing that the relationship between investment and q is no longer linear. In that case optimal investment can be characterized by a threshold rule: for values of q above some upper threshold (q_2), investment is positive and increasing in q, for values of q below some lower threshold (q_1), optimal investment is negative and is an increasing function of q. For values of q between the two thresholds, investment is zero, and this range is known as the range of inaction.

Even though previous studies assumed symmetric quadratic costs of adjustment, thereby obtaining a linear relationship between the investment rate and q, in this paper we explicitly consider the possibility of non-convex adjustment costs and of a non-linear relationship. We allow this relationship to vary across regimes defined by the level of q. We test for the presence of non-linearities in investment behavior following Abel and Eberly (1994), Barnett and Sakellaris (1998) and Nilsen and Schiantarelli (2003). Besides, variables that were not supposed to appear in investment equations, such as cash flow, are found to play a significant role, highlighting the effect of financing imperfections on investment (e.g. Kiyotaki & Moore 1997, Lorenzoni & Walentin 2007, Hennessy et al., 2007). In a more recent study, Abel and Eberly (2011) build a closed form analytical model with perfect capital markets and show that even in the absence of financing constraints, investment remains sensitive to both Tobin's q and cash-flow, undermining the traditional interpretations of empirical investment equations.

Our approach specifies a dynamic model of investment at the firm level in order to get a better understanding of microeconomic investment decisions made by Greek firms. Actually, the aim of the paper serves as a guideline for managers in order to investigate the effects of both convex and non-convex adjustment costs of capital investment decision making process. In addition, the effect of financial flexibility is a major issue for the majority of managers' in the U.S. and Europe list listing it as the most important goal of their firms' financial policies. Especially, the selected period is probably the ideal one as within this timeframe firms experienced a huge increase which was immediately followed by a violent and sharp drop despite the at the time market's irrelevance to the actual macroeconomic environment. The rest of the paper is structured as follows. In the next section we review the Tobin's q by providing theoretical and empirical implications. In Section 3 we discuss the econometric methodology that we use. In Section 4 and Section 5 we present the data used and the empirical results and discuss them. Finally, Section 6 concludes.

2. LITERATURE REVIEW

2.1. The *q* theory approach

A variety of theories have been developed to explain investment behaviour (for surveys refer to Chirinko, 1993; Caballero, 1999). The economic models of business fixed investment can be classified into two classes. The distinguishing feature is whether or not the model takes under consideration the process of adjustment of the capital stock. In both classes of models the optimal level of the firms' capital stock results as the main solution of the profit maximization problem. However, the older and classical models (Jorgenson, 1963; 1971) do not explain the optimal path of capital, but the second class of models derives the optimal evolution of the capital stock from the underlying optimization problem. Hence, the difference can be seen in the step from the static problem of optimal factor demand to dynamic investment models. This can be performed either by ad hoc specifications or by an explicit derivation of the adjustment path undertaken in the investment models based on the q theory.

Tobin (1969) defines q as the market value of the firm divided by the replacement cost of its capital. According to this metric, a high value of q implies that companies can issue stock at a favourable price compared to the cost of new plant and equipment. Therefore, new investment is attractive (the firm will undertake a project) provided that q is greater than unity. If however, q was less than unity it would be more financially attractive to buy another firm cheaply and acquire existing capital. The standard q model describes the investment behavior of a competitive firm subject to constant returns to scale and strictly convex costs of adjusting its capital stock. Unfortunately, the theoretical appeal of q investment theory has not been matched by its empirical success. The theoretical model requires the measurement of a project's marginal q, however typically data considerations allow the researcher to only calculate the average[2] q. This is inherently flawed since it reflects the average return on a company's total capital, whereas it is the marginal return on capital that is relevant (Chirinko & Schaller, 1995). However, if the Hayashi[3] conditions are not satisfied, or 'bubbles' (Blanchard and Watson, 1982) or liquidity traders (Campbell and Kyle, 1993) influence stock market valuations, then Tobin's q would not capture all relevant information about the expected future profitability.

2.2. Brief review of the empirical studies

More recently, a number of empirical studies have estimated models with non-convex adjustment cost for firm-level panel data. Caballero et al. (1995) estimate an "effective hazard function" relating investment to the gap between the plant's actual capital stock and an estimate of its desired capital stock. They find that the estimated hazard function is not flat, but increasing over some range of this gap, highlighting that the investment response is non-linear. Furthermore, Eberly (1997), for a sample of eleven countries finds economically significant evidence of a non-linear relationship between investment and fundamentals, consistent with the presence of fixed costs or other non-quadratic costs of investment. Bloom et. al. (2007) examine the effect of non-convex adjustment costs on the responsiveness of investment. They find that higher uncertainty reduces the responsiveness of

[2]See the full development of the mathematical approach in Appendix B.
[3]The Hayashi conditions are: perfect competition, constant returns to scale and strictly convex adjustment costs, under which average q is a sufficient statistic for investment rates.

investment to demand shocks – and that these "cautionary effects" are large. In this line, Lapatinas (2007) for a sample of 1419 Greek firms from 1996 to 2002 emphatically rejects the neoclassical model with convex adjustment costs only and buttresses up the argument that adjustment costs are more complex than we once thought. He also founds that frictions are important in determining a firm's investment dynamics and traditional models with convex costs of adjustment seem to be incapable of capturing the dynamics of investment and capital accumulation. Barnett and Sakellaris (1998) also document a non-linear relationship between firm investment and q, showing empirically that investment is concave in q. In particular, they show that investment responds significantly to average q at relatively low values of q, but little at high values. This is in contrast to the predictions of the Abel and Eberly (1994) model, who conclude that investment will react to q only when q exceeds a threshold value.

Doms and Dunne (1998) examine investment on manufacturing plants finding evidence of lumpy investment at the plant level and argue that this is consistent with models of non-convex adjustment costs. Caballero and Engel (1999) use two-digit manufacturing data on investment to estimate a model in which firms face stochastic fixed costs of investment. Their evidence suggests that fixed costs are playing a prominent role in the investment for the analyzed firms, and therefore, incorporating these costs improves the predictive ability of investment models. Cooper et al. (1999) examine the implications of a model of machine replacement, focusing on the extensive investment margin and the age of equipment in place. They document that investment is largely determined by aggregate shocks affecting the number of plants investing. In addition, Barnett and Sakellaris (1999) find that firm's investment rate is more responsive to expected future q the higher the level of this q, i.e. investment is a convex function of fundamentals. Honda and Suzuki (2000) investigate the investment threshold for large Japanese manufacturing firms using marginal q, and support that investment function is indeed non-linear. They find the overall threshold level for q to be about 1.62, a number that falls in between the corresponding estimates (1.13 and 1.95) reported in the Barnett and Sakellaris (1998) study, and a satiation point of 3.75.

In this line, Nilsen and Sciantarell (2003) using Norwegian microdata estimate a switching regression model which allows for the response of investment to differ across regimes. They suggest a two-regime approach where the response of investment to fundamentals is close to zero for low values of fundamentals and high above a threshold. Finally, when exploring for other fundamentals as well, Bolton et al. (2011) show that investment depends on the ratio of marginal q to the marginal value of liquidity highlighting the central importance of cash and credit line for corporate decisions. In this line, Ajide (2017) for a panel of Nigerian firms finds that cash flow as an internally generated fund displays positive relation with corporate investment when q is included in the estimation process a results that support those of Lang et al. (1996) and Aivazian et al. (2005) using US and Canadian data respectively. Simmons-Süer (2018) using the Markov regime-switching methodology to examine the interactions between the cost of capital, investment, and Tobin's q and shows that cost of capital influences the way investment reacts to Tobin's q across different regimes. Essentially, he concludes that the availability of the external financing instruments to a company is not irrelevant, and constraints arising from capital market imperfections should not be ignored.

3. ECONOMETRIC METHODOLOGY

3.1. The linear investment specification. The restricted models

The first specification estimated is the standard linear investment equation, which serves as a benchmark for comparison to earlier studies and to the non-linear estimates that will follow in this section. Thus, we develop a model of investment utilizing the framework of the q model, based on the assumption of convex adjustment costs. Under the assumption of perfect competition, constant returns to scale, and capital as the only quasi-fixed factor, marginal q is equal to average q. Conditional on average q no other variable should have any explanatory power for investment. However, many empirical studies of investment reject this implication by finding that cash flow has a significant effect on investment, even if q is included as an explanatory variable. This finding has been interpreted by Fazzari et al. (1988) among others as evidence for the presence of financial constraints.

Given the discussion above, the standard linear investment function relating investment to Tobin's q and cash flow is given as shown below[4,5]:

$$\begin{aligned}\Delta(IK)_{i,t} = \beta_0\left[\Delta(IK)_{i,t-1}\right] + \beta_1\left[\Delta(q)_{i,t-1}\right] + \Gamma\left(X_{i,t}\right) \\ + \sum_{t=1993}^{2001} \tau_t \text{ (time dummies)} \\ + \varepsilon_{it} - \varepsilon_{i,t-1}\end{aligned} \quad (1)$$

where i identifies firm, t refers to the time period (annual intervals), Δ denotes the first difference operator (applied to eliminate firm-specific components), β'_s, τ'_s are unknown parameters to be estimated, and finally ε is a white noise disturbance term. Investment expenditure is denoted by IK, q stands for Tobin's q and K is the beginning-of-period capital stock[6], Γ is a matrix of parameters, and X is a vector of firm-specific variables that includes cash flow, age and size. To account for unobserved time effects, time dummies are also included.

Under the validity of the standard Tobin's q, which suggests a positive and monotonic relationship between investment and q we expect β_1 to be significantly positive.

A more general functional form has also been considered in the literature, where essentially Equation 1 is augmented by the inclusion of the

[4] The equation appears in first-differences form and the error term structure appears as $\varepsilon_t - \varepsilon_{t-1}$ since at the estimation stage the parameters will be estimated by the GMM Arellano-Bond (1991) method. Detailed description of the method will be provided in a later section.

[5] q enters the model lagged one period to ensure correct timing of information (for more details see Eberly, 1997).

[6] A detailed description of the variables appears in the Data section.

squared term of q, in order to capture potential curvatures in the investment- q relationship:

$$\Delta(IK)_{i,t} = \beta_0[\Delta(IK)_{i,t-1}] + \beta_1[\Delta(q)_{i,t-1}] + \beta_2\,[\Delta(q)^2_{i,t-1}] + \Gamma(X_{i,t}) + \sum_{t=1993}^{2001} \tau_t\,(time\ dummies) + \varepsilon_{it} - \varepsilon_{i,t-1} \qquad (2)$$

3.2. Unrestricted model: Allowing a two-regime model

At this part we depart from the standard convex adjustment cost framework and investment reversibility that underlies the q theory of investment. It can be shown that such departures may lead to the prediction that investment responds to q discontinuously and possibly at varying speeds across the domain of q. For instance, Abel and Eberly (1994) advocate that when fixed adjustment costs and irreversibility of investment are incorporated in the neoclassical model with convex adjustment costs, the relationship between fundamentals and investment becomes nonlinear. In this framework, there are regions where investment in a homogeneous capital good is insensitive to q as well as regions where it is responsive to q. In their model they propose, three regions indicating three different regimes: for low values of q investment may be negative, for intermediate values of q it may be zero (inaction range), and for high values of q it may be positive.

Therefore, if one is interested in a direct testing of the Abel and Eberly (1994) model, the adopted empirical specification should explicitly allow investment responses to the level of q to be different across the three regimes. There is an apparent need for identifying the levels of q, which operate as the thresholds that essentially define the three regions as discussed above. Provided that these thresholds were known, it would be straightforward to empirically assess whether the response of investment differs across these regions. In fact, Abel and Eberly (1994) offer a rough qualitative guide regarding the pattern of responses: zero for the inaction range, positive for the two remaining ranges and also suggesting an increasing response as q enters its highest range. Note the differences as well as the similarities with the standard q model predictions: unity acts as a threshold of indifference for firms, while different values from unity compel some sort of action from the part of firms; below unity disinvestment, above unity investment.

However, the econometrician is confronted with unknown thresholds as well as testing for the differential response of investment across the regimes defined by these thresholds. In other words, the locations of these regimes hosting the variable response are unknown. Barnett and Sakellaris (1998) follow an econometric method that allows them to jointly identify the threshold points as well as testing for the possibility of non-linear responses of investment.

In our sample though, there are very few observations with either negative or zero investment, rendering it virtually impossible to estimate a three regime model. Table 1 below shows the sample distribution of investment rates across various percentiles indicating that positive investment rates represent the 83 per cent of the observations.

Table 1. Distribution of investment rates

Investment rates	*Percent*
<0	17%
=0	0%
0< <0.05	27%
0.05≤ < 0.10	15%
0.10 ≤ < 0.20	15%
0.20 ≤ < 0.30	9%
0.30 ≤	17%
Total	*100%*

Following Eberly (1997) and Nilsen and Schiantarelli (2003)[7] who faced a similar problem, since only positive investment rates were used in their studies, we resort to estimate a two-regime model with a high and a low q regime. We expect firm investment to be more responsive to variation in fundamentals in the high q regime. By the same token, investment in the low q regime is expected to show lower responsiveness, without imposing a zero response. Thus, it is apparent that investment is allowed to respond differently depending on whether the value of q lies in the low or the high regime. In other words, there is a threshold, $\tilde{q}$, which separates the two non-overlapping regimes. Hence, investment behaves according to the following function:

$$IK = \begin{Bmatrix} g(q), & iff \quad q \leq \tilde{q} \\ h(q) & iff \quad q > \tilde{q} \end{Bmatrix} \qquad (3)$$

where $g(q)$ and $h(q)$ are allowed to be either linear or quadratic functions. We expect $g'(q)$ to be lower than $h'(q)$.

In order to locate the threshold, we employ a method, in the spirit of Barnett and Sakellaris (1998), where the threshold and thus the regimes are exogenously selected. In order to minimize the potential losses from an erroneously selected threshold we consider three alternative sets of regimes ‘sliding’ across the sample distribution of q. The three alternative thresholds ($\tilde{q}$) are defined as follows: (30th percentile), (50th percentile) and (80th percentile). Once the threshold is imposed, the task of investigating possible non-linearities across regimes is rather straightforward and pursued by the use of a set of indicator functions as follows:

$$\begin{Bmatrix} D_1 = 1 & iff \quad q \leq \tilde{q}, zero\ otherwise \\ D_2 = 1 & iff \quad q > \tilde{q}, zero\ otherwise \end{Bmatrix} \qquad (4)$$

Utilizing this set of dummies the model takes the following form[8]:

[7] Note that Nilsen and Schiantarelli (2003) adopt an alternative estimation strategy, applying a regime switching model. Our method although not identical, is similar in spirit.
[8] The inclusion of the squared term of q will ensure that our estimation does not confuse a single regime but non-linear with a two-regime case.

$$\begin{aligned}\Delta(IK)_{i,t} = \beta_0\left[\Delta(IK)_{i,t-1}\right] + \beta_1\left[\Delta(q)_{i,t-1} \times D_1\right] \\ + \beta_2\left[\Delta(q)^2_{i,t-1} \times D_1\right] \\ + \beta_3\left[\Delta q_{i,t-1} \times D_2\right] \\ + \beta_4\left[\Delta q^2_{i,t-2} \times D_2\right] + \Gamma\left(X_{i,t}\right) \\ + \sum_{t=1993}^{2001} \tau_t\,(time\ dummies) \\ + \varepsilon_{it} - \varepsilon_{i,t-1}\end{aligned} \quad (5)$$

3.3. The GMM estimation technique

Equations 1, 2 and 5 are estimated using the Generalised Method of Moments (GMM, hereafter) where lagged levels of the dependent variable and the independent variables are used as instruments (Arellano & Bond, 1991). The first difference GMM estimator is appropriate since it controls for biases due to unobserved firm-specific effects and the endogeneity of explanatory variables. Given that the errors $\varepsilon_{i,t}$ are not serially correlated, the lagged levels dated *t-2* and earlier of the dependent variables and the independent variables are valid instruments. The estimation imposes the following linear moment restrictions[9]:

$$E\left[(\varepsilon_{i,t} - \varepsilon_{i,t-1})Z_{i,t-k}\right] = 0 \quad (6)$$

where *k=2,…,K* and *Z* is a vector of instruments.

Arellano and Bond (1991) propose a test for examining first order, m_1, and second order, m_2, serial correlation of the differenced residuals. Also, we use the Sargan (1958) test to determine the validity of instruments, which is based on the over identifying restrictions appearing in Equation 6. Under the null hypothesis of valid instruments, it is asymptotically distributed as χ^2.

4. DATA DESCRIPTION

The data used in this study are based on balance sheets of all non-financial firms listed in the ASE (Athens Stock Exchange) for the period 1993-2001. The source is the Yearly Statistical Bulletin, published by the ASE[10]. A total of 273 firms have been traded during this period. The dataset consists of an unbalanced panel since the number of listed firms varies from year to year. The selection of the period was made on purpose as the years between 1999-2000, a large number of overvalued and overpriced stocks, were collapsed, affecting the whole market. This previous period is considered as the biggest bubble in the Athens Stock Exchange history and in the end investors were mercilessly hammered writing off substantial losses. Of course the analysis of markets' volatility is more common during economic crises as the most recent one and especially the period 2008-2010, however the fact that the collapse of 1999-2000 took place within a growing economic environment and right before the joining of the single currency makes it even more interesting. Despite the unprecedented drop of 1999-2000 the fundamentals of the economy were not harmed dramatically and the country successfully joined the Eurozone a year after.

For each year we include the universe of firms in order to avoid introducing survivorship bias into our sample[11]. Using firm-level data has several advantages: (i) it avoids aggregation problems, (ii) the cross-sectional variation in q helps to provide more accurate estimates of the parameters, and (iii) the variables used in the construction of q can be more precisely measured at the firm level, especially when using the share prices of individual firms provides a direct measure of equity value.

Essentially, for the unrestricted model, we dichotomize the sample distribution of q at two alternative potential segments. In other words, we exogenously impose and test the presence of three alternative thresholds, which are the following: (30^{th}), (50^{th}), and the (80^{th}) percentiles. Thus, the optimal investment behavior of the firm can be characterized by potentially two-regimes, where the values of q could be either below the threshold $\tilde{q}$, or above.

As far as for the variable definitions are concerned, investment *IK* is defined as the annual change in fixed assets minus sales and disposals, while Tobin's q has been computed following the methodology outlined in Salinger and Summers (1983)[12]. *CF* represents internal funds, measured as the sum of net operating profits and depreciation ratio. Finally *AGE* is defined as the logarithm of the number of years since foundation, while *SIZE* is calculated as the logarithm of the value of total assets. Investment and cash flow have been divided by the beginning-of-period capital stock *K*. Summary statistics for the variables used in the regressions are included in Table 2 and the construction of variables in included in Appendix C.

5. EMPIRICAL RESULTS

Applying the GMM dynamic panel estimation technique we estimate the parameters of Equation 1 and report the results in column 2 of Table 3 (see Appendix A).

The residuals satisfy the over-identifying restrictions, which are not rejected (see Sargan test) suggesting that the model is well specified, and furthermore there is no sign of second-order autocorrelation[13]. According to our results, the coefficient on Tobin's q is positive and significant. This finding suggests that the null hypothesis of no response of q on investment is strongly rejected (t-stat: 3.52).

In terms of the remaining estimated parameters, past investment is insignificant for current investment. Inspecting the remaining three conditioning variables, size affects investment significantly, with larger firms on average tending to be associated with a higher investment rate. The coefficient of age turns out to be negative and significant. Finally, cash flow exerts a significantly

[9] Equivalent restrictions apply for the error terms in Equations 1 and 2.
[10] Banks, Leasing, Holding and Insurance companies were excluded from the sample. Four companies whose stock was under suspension were also excluded.

[11] The only potential source of survivorship bias is due to disappearance of firms from our sample due to firms exiting the stock market. During the period under scrutiny the number of firms leaving the ASE was less than 0.5 per cent.
[12] Tobin's q represents the investment opportunities facing the firm. Average q is measured as *q=(E+TDBT-INV)/PK*, where *E* represents the sum of the value of the firm's common and preferred stocks, *TDBT* represents the total debt of the firm and *INV* is the value of the firm's inventories. *PK* is the replacement cost of the firm's capital stock, which is measure following Salinger and Summers (1983).
[13] The relevant test detects significant first-order autocorrelation in the residuals. This was expected given the fact that the model is formulated in first differences and consequently the resulting disturbance term exhibits first-order autocorrelation by construction.

positive impact on investment highlighting the presence of imperfections in the Greek capital market. This finding suggests that the significance of cash flow variable conditioning on Tobin's q investment equation can be attributed to the failure of Tobin's q to capture all relevant information for expected future profitability of current investment projects. The high sensitivity of investment decisions of firms to liquidity is a recurring theme in the empirical literature, which is quite robust across different periods and countries (Fazzari et al., 1988; Whited, 1992; Schaller, 1993; Bond & Meghir, 1994; Vermeulen, 2002; Vijverberg, 2004). Hence, the fact that cash flow has a positive impact on investment, even after taking account of q, is often interpreted as evidence of financing constraints facing firms (Abel, 2018).

Column 3 in Table 3 reports estimates of an augmented version of model (1) as it appears in Equation 2, where we account for the lagged square term of q in order to allow for a quadratic relationship between investment and q. The square term coefficient in column 3 is negative and statistically significant indicating that the investment rate is concave to q. The concavity established is consistent with the model of non-convex adjustment costs, since if the adjustment costs were symmetric and quadratic the coefficient on the squared term would be zero (Eberly, 1997; Barnett & Sakellaris, 1998; Abel & Eberly, 2001; Bond & Cummins, 2001). The results for the rest of the parameters remain largely unchanged.

In Table 4 we report estimation results obtained from Equation 5 where we allow for a two-regime model while considering three alternative thresholds which are the following: (30), (50), and (80) percentiles[14].

First, we consider the possibility that the threshold is located at the 30th percentile of the sample distribution of q (column 2b). Our estimates indicate that the response of investment in the region below the threshold (Regime 1) is highly insignificant (with a p-value 0.62), while in contrast the response above the threshold (Regime 2) is highly significant (with a p-value 0.00). Thus, we obtain prima facie evidence for the presence of more than one regime. Notice that the square term for the above- threshold region attains a significantly negative value providing further evidence for a concave relationship between investment and fundamentals, i.e. non-convex adjustment costs.

Next, we consider whether the area of zero responsiveness of investment is extended further in the distribution. We do so by testing whether the threshold is located at the 50th percentile (column 3b). Our estimation provides support for an extended region of zero responsiveness (with a p-value 0.16), while reconfirming our previous inference of more than one regime present, with the second one starting at least from the 50th percentile (with a p-value 0.00). The concavity finding is also retained. Finally in column (4b), using the 80th percentile as the potential threshold our results show that investment responds significantly in both regimes. This finding coupled with the previous ones, essentially rules out the possibility that the zero responsiveness of investment extends up to the 80th percentile. This led us to extend the threshold by an extra 10 per cent, considering the 60th percentile. The results in column 5b suggest that when the 60th percentile is considered as a potential threshold, investment responds positively to fundamentals in both resulting regimes. At first sight, this result might seem paradoxical, however to some extent it was expected. Recall, that the response of investment for above the 30th region was strongly significant and for the below 50th region insignificant, albeit with a low p-value (0.16). These imply that investment starts to exhibit some sort of sensitivity to fundamentals after the 30th percentile, although not vigorous enough to be statistically significant. Consequently, when the 60th percentile is considered then the undisputed significant response above the 50th percentile along with the less significant response above the 30th percentile result in an overall statistically significant coefficient. Thus, we conclude that the zero sensitivity area is adequately described as being below the sample median of q.

Let us recap our findings so far. The investment- q relationship is neither continuous nor linear, since it alternates between zero and positive slope around the 50th percentile of the q distribution and also we find strong evidence for a decreasing slope (non-convexity of adjustment costs). The 50th percentile in terms of q corresponds to a value of approximately 2.00 implying that, contrary to the standard Tobin's theory, the trigger point for the sample of Greek listed companies considered here is higher than unity. This comes hardly as a surprise considering the point made by Dixit and Pindyck (1994) that firms invest in projects that are expected to yield a return typically three or four times the cost of capital. Overall, the results outlined above following the existing literature (e.g. Bloom, 2007; Lapatinas, 2007; Simmons-Süer, 2018 etc.) provide strong evidence against the neoclassical model with convex adjustment costs. In particular, Our results are also in line with the empirical studies of Nilsen and Schiantarelli (2003) who report higher sensitivity of investment to fundamentals in the high regime and also find strong evidence for concavity. Barnett and Sakellaris (1998) who directly test the implications of the Abel and Eberly (1994) model do find evidence for three regimes but fail to confirm the model predictions in terms of the monotonicity of coefficients. In particular, they conclude that the middle regime coefficient is positive (while expected to be zero), but also turns out to be larger than the corresponding coefficient of the third regime. Our results are also in line with the study by Honda and Suzuki (2000) who set up an econometric model in order to estimate the investment thresholds of large Japanese manufacturing firms. In particular, they conclude that the threshold level for q, which triggers investment, is about 1.62. In addition, their analysis allows the estimation of the satiation point, above which corporate investment slows down, which is found to be at 3.75.

6. CONCLUSION

Using a dataset comprising of non-financially related firms listed in the ASE for the period 1993-2001 we addressed a set of research questions focusing on

[14] We also estimated a version of the model excluding the quadratic term, but the results remain unchanged and for space considerations are reported in Table 4, and no discussed in the text. Note however that concavity is in general supported by the data.

nonlinearities of investment responses to q. In particular, we empirically investigate whether these responses vary with the level of q. We find significant evidence for a non-linear relationship between investment and fundamentals, taking two forms: a) a discontinuity identifying two-regimes, wherein the first (for values of q below a certain threshold) investment is inelastic to q, while in the second it exhibits a positive relationship, and b) a further non-linearity expressed in a concavity of the investment- q relationship, which implies that for the segment where investment reacts to fundamentals positively, it does so at a decreasing rate evidence which is consistent with the presence of non-convexities in adjustment costs.

Overall, our results provide some practical ideas regarding the investment dynamics of firms. The presence of cash flow availability influences a firm's optimal investment, financing, and risk management policies. This is of vital interest for managers dealing with firms' investment opportunities. Hence, both liquidity management and investment decisions are complementary management tools. It is more than apparent, that the above concerns can provide extensive food for thought for managers and the investment decision process within firms.

Based on our current estimates we can see a few directions for related future research. The recent financial crisis suggests that market conditions can change sharply and thus the firms' investment policy. Probably, the inclusion of more frictions other than the cash flow dynamics would enrich our model to accommodate the recent events. Besides a more combined approach would be to explore whether the presence of non-convexities at microeconomic level matters for aggregate investment and effectively can affect the business cycle. Finally, the general factor of demand could be also investigated by using labour instead of capital, an approach that has already attracted much attention.

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APPENDIX A

Table 2. Descriptive statistics

	Investment				***Tobin's q***			
	Whole Sample	*30%*	*50%*	*80%*	*Whole Sample*	*30%*	*50%*	*80%*
Mean	0.16	0.23	0.20	0.18	3.12	0.42	0.85	1.75
Min	-0.74	-0.21	-0.6	-0.6	-4.58	-4.58	-4.58	-4.58
Max	3.73	2.62	2.66	2.66	19.1	1.07	2.03	4.99
St.Dev	0.30	0.39	0.37	0.32	3.36	0.56	0.71	1.38
Obs	1325	265	448	742	935	280	467	748

Notes: Descriptive statistics based on the whole sample distribution and on each threshold.

Table 3 Linear/Quadratic specifications: investment and Tobin's q model (dependent variable *IK*, number of observation 397, number of groups 149, period 1993-2001)

Regressor (1)	***Linear (2)***	***Quadratic (3)***
$\Delta(CF_{it})$	0.76*** (0.00)	0.75*** (0.00)
$\Delta(IK_{i,t-1})$	-0.01 (0.61)	-0.01 (0.61)
$\Delta(q_{i,t-1})$	0.012*** (0.00)	0.03*** (0.00)
$\Delta(q_{i,t-1}^2)$	-	-0.0017*** (0.00)
$\Delta(AGE_{i,t})$	-0.32** (0.03)	-0.27* (0.06)
$\Delta\ (SIZE_{i,t})$	0.74*** (0.00)	0.75*** (0.00)
Time dummies	Included	Included
Diagnostics		
m_1	-2.92*	-1.89*
m_2	0.22	0.22
Sargan (27 Moment conditions)	29.78 (p-value: 0.32)	27.08 (p-value: 0.45)

Notes: (1), (2), and (3) denote columns. Values in brackets denote p-values, m_1 and m_2 are first-order and second-order serial correlation tests, while Sargan stands for the over-identifying restrictions test. Numbers in square brackets denote p-values. One, two and three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Table 4. Threshold regressions for Tobin's q: two-regime approach (dependent variable,number of observation 397, number of groups 149, period 1993-2001)

	(30)		***(50)***		***(80)***		***(60)***	
	(2a)	***(2b)***	***(3a)***	***(3b)***	***(4a)***	***(4b)***	***(5a)***	***(5b)***
Regressor	***Linear***	***Quadratic***	***Linear***	***Quadratic***	***Linear***	***Quadratic***	***Linear***	***Quadrati c***
Regime I								
$\Delta(q_{i,t-1}) \times D_1$	-0.013 (0.66)	0.01 (0.62)	-0.01 (0.50)	0.02 (0.16)	0.02*** (0.00)	0.04** (0.02)	0.006 (0.60)	0.04*** (0.00)
$\Delta\ (q_{i,t-1})^2 \times D_1$	-	-0.002 (0.59)	-	-0.0052 (0.35)	-	-0.00004 (0.98)	-	-0.0009 (0.83)
Regime II								
$\Delta(q_{i,t-1}) \times D_2$	0.012*** (0.00)	0.03*** (0.00)	0.01*** (0.00)	0.03*** (0.00)	0.01*** (0.00)	0.03*** (0.00)	0.01*** (0.00)	0.04*** (0.00)
$\Delta(q_{i,t-1})^2 \times D_2$	-	-0.0017*** (0.00)	-	-0.0016*** (0.00)	-	-0.0016*** (0.00)	-	-0.0017*** (0.00)
Diagnostics								
m_1	-1.93*	-1.89*	-1.91*	-1.88*	-1.91*	-1.87*	-1.91*	-1.88*
m_2	0.21	0.21	0.21	0.21	0.22	0.22	0.24	0.20
Sargan (27 Moment conditions)	29.46 (0.33)	26.84 (0.47)	28.40 (0.39)	26.45 (0.49)	29.35 (0.34)	26.74 (0.47)	30.11 (0.30)	27.54 (0.43)

Notes: (2a), (2b), (3a), (3b), (4a) and (4b) denote columns. In all equations we control for IK, CF, AGE and SIZE. Values in brackets denote p-values, $m_1$and m_2 are first-order and second-order serial correlation tests, while Sargan stands for the over-identifying restrictions test. Numbers in square brackets denote p-values. One, two and three asterisks denote significance at the 10, 5, and 1 percent level respectively.

APPENDIX B

Closely following Bond and Cummins (2001), the main firm's objective is to maximize:

$$V_t = E_t\left[\sum_{s=0}^{\infty} \beta_{t+s}\Pi_{t+s}\right] \tag{1B}$$

where Π_{t+s} denotes net revenue generated in period *t+s;* β_{t+s} is the discount factor used in period *t* to discount expected revenue in period *t+s,* with $\beta_t = 1$ and $E_t[.]$ the expectation operator conditioned on information available in period *t.*

We specify the net revenue function as having the form:

$$\Pi_t(K_t, L_t, I_i) = p_t F(K_t, L_t) - w_t L_t - p_t^k[I_t + G(I_t, K_t] \tag{2B}$$

where K_t is the stock of capital in period *t,* L_t denotes a vector of variable inputs used in period *t,* I_t, is gross investment in period *t,* p_t, is the price of the firm's output, w_t is a vector of prices/wage rates for the variable inputs, and p_t^k is the price of capital goods in period *t.* $F(K_t, L_t)$ is the production function and $G(I_t, K_t)$ is the adjustment cost function. Our timing assumption is that current investment is immediately productive, and the stock of capital evolves according to:

$$K_{t+s} = (1-\delta)K_{t+s-1} + I_{t+s} \tag{3B}$$

where δ is the rate of depreciation. We also assume that current prices and the realizations of current technology shocks are known to the firm when choosing current investment. The expected value in Equation (1) is taken over the distribution of future prices and technology shocks. Other timing conventions are certainly possible, but would not affect the substance of our analysis in the following sections.

The firm chooses investment to maximize $V_t$subject to the capital accumulation constraint in Equation (3). The first order conditions for this problem give:

$$-\left(\frac{\partial \Pi_t}{\partial I_t}\right) = \lambda_t \tag{4B}$$

and

$$\lambda_t = E_t\left[\sum_{s=o}^{\infty} \beta_{t+s}\,(1-\delta)^2\left(\frac{\partial \Pi_{t+s}}{\partial \mathrm{K}_{t+s}}\right)\right] \tag{5B}$$

where λ_t is the shadow value of an additional unit of installed capital in period *t.* Given Equation (2) and price-taking behaviour, the first order condition (4) can be rearranged as:

$$\left(\frac{\partial G_t}{\partial I_t}\right) = (q_t - 1) \tag{6B}$$

where $q_t = \lambda_t / p_t^k$ is the marginal *q,* or the ratio of the shadow value of an additional unit of capital to its purchase cost. In the absence of adjustment costs, investment is chosen such that marginal *q* is unity, and in the presence of strictly convex adjustment costs investment is an increasing function of marginal *q.*

The average *q* model requires that $\Pi_t(K_t, L_t, I_t)$ is homogeneous of degree one in (K_t, L_t, I_t), sufficient conditions for which are that both the production function and the adjustment cost function exhibit constant returns to scale, and the firm is a price taker in all markets. Given this linear homogeneity, Hayashi (1982) proved the equality of marginal *q* and average *q,* which with our timing convention yields:

$$q_t = \frac{V_t}{p_t^K\,(1-\delta)K_{t-1}} \tag{7B}$$

Average *q* is the ratio of the value of a firm entering period t with a capital stock of $(1-\delta)K_{t-1}$ inherited from the past, to the replacement cost value of that capital in period *t.* Notice that the numerator of average *q* in (7) is the present value of current and expected future net distributions to shareholders, as in Equation (1). As noted in the introduction, the firm's stock market valuation need not coincide with this fundamental value, even if stock markets satisfy weak and semi-strong forms of the Efficient Markets Hypothesis, as defined by Fama (1970).

Further assuming that adjustment costs have the symmetric, quadratic form:

$$G(I_t, K_t) = \frac{b}{2}\left[\left(\frac{I_t}{K_t}\right) - c - e_t\right]^2 K_t \tag{8B}$$

then gives the conventional linear model:

$$\left(\frac{I_t}{K_t}\right) = c + \frac{1}{b}\left(\frac{V_t}{p_t^K(1-\delta)K_{t-1}} - 1\right) + e_t = c + \frac{1}{b}Q_{t+}e_t \tag{9B}$$

in which the error term e_t is an adjustment cost shock, observed by the firm but not by the econometrician, which may be serially correlated.

APPENDIX C

Construction of the variables

IK: Investment is measured as the annual change in fixed assets minus sales and disposals.
SK: Sales capital ratio. Sales are measured by the sales variable (Turnover) in BACH.
CF: Cash Flow. Cash Flow is measured as gross operating profit (net operating profit plus depreciation).
AGE: is calculated as the logarithm of the number of years since foundation.
SIZE: is calculated as the logarithm of the value of total assets $q = (E + TDBT - INV)/PK$.
Tobin's q: is measured as Investment and cash flow have been divided by the beginning-of-period capital stock K, which K is measured by Intangible and Tangible Fixed Assets.