Firm Market Value and Investment: The Role of Market Power and Adjustment Costs*

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Abstract

Barnett and Sakellaris (1999) show that the responsiveness of investment to Tobin's Q is highly nonlinear, using a modified neoclassical investment model with linearly homogenous profit and capital adjustment cost functions, both of which are questioned by recent studies. In this paper, a dynamic investment model with convex and nonconvex adjustment costs as well as firm market power is simulated to replicate the empirical results of Barnett and Sakellaris in order to better understand the foundations of empirical results based on Q-theory models. The structural parameters of the model are estimated using an indirect inference methodology.

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1 Introduction

Since investment is one of the most volatile and important components of output, a special emphasis is given on this topic in the economic literature. Many different models have been introduced to study the investment behavior of firms, but the most extensively investigated models have been Tobin's Q theory and the neoclassical theory of investment with convex adjustment costs.[1] These models theoretically relate investment to different economic fundamentals such as firm market value.

Many empirical studies have been conducted in these theoretical frameworks. In most studies, empirical specifications have been based on two simplifying linear homogeneity assumptions: the profit function is homogenous of degree one in capital; and the capital adjustment cost function is homogenous of degree one in investment and capital. These assumptions produce the following two simplifying results: 1) empirically observable average Q is equal to the expected marginal Q which is not empirically observable; and 2) estimated coefficients from regressing investment on average Q give information about the structural parameters of convex adjustment costs.

The initial empirical results were disappointing since fundamentals were found to be unsuccessful in explaining investment even though they were supposed to be the sole determinant of investment. The other set of disappointing results was related to the regression results producing unreasonably large adjustment cost coefficients due to the low responsiveness of investment to fundamentals.

One possible explanation for the failure of Q-theory has come from a group of studies emphasizing the importance of nonlinearities in the invest-

[1] See Jorgenson (1963), Tobin (1969), Lucas (1967), Mussa (1977), Abel (1980), Hayashi(1982), Abel (1990).

ment process.[2] In this group of studies, Doms and Dunne (1998) show that in a sample of U.S. manufacturing establishments about 72 percent of a typical establishment's total investment over 17 years is concentrated in a single year. Caballero, Engel and Haltiwanger (1995) and Caballero and Engel (1999) show that investment response to fundamentals, measured by the gap between actual and desired capital stock, is disproportionately larger for a larger gap. Cooper, Haltiwanger and Power (1999) and Nilsen and Schiantarelli (2000) provide evidence that the hazard of a large investment "spike" is increasing in the years since the last investment "spike." Barnett and Sakellaris (1998), Barnett and Sakellaris (1999), and Abel and Eberly (2002*a*) find that investment responsiveness to Tobin's Q is highly non-linear.

While explaining the nonlinear responsiveness of investment to fundamentals, the investment literature has basically followed two alternative ways in terms of investment models used. On the one hand, some studies have remodeled the investment behavior of firms by changing the structure of Q-theory models and excluding simplifying assumptions listed above. The inclusion of non-convex adjustment costs takes place in this group of studies.[3] Specifically, irreversibilities and/or fixed costs of investment may lead firms to experience episodes of zero investment as well as large investment in response to similarly small movements in fundamentals, which is in contrast to what is expected from convex adjustment cost models which produce pro-

[2] Another major group of studies tries to explain the failure of Q-theory by the presence of financial constraints. They argue that fundamentals are not successful in explaining investment since financial variables such as profit or cash flow may be a more important determinant of investment in the presence of financial frictions. See Meyer and Kuh (1957), Schiantarelli (1996), Fazzari, Hubbard and Petersen (1988), and Hubbard (1998). On the other hand, Kaplan and Zingales (1997), Gomes (2001), Erickson and Whited (2000), Cooper and Ejarque (2003*a*), and Abel and Eberly (2003) question the significance of financial variables in determining investment.

[3] An important paper by Cooper and Haltiwanger (2003) solves a structural investment model in the presence of both convex and fixed adjustment costs in plant-level investment activities in US manufacturing.

portional responses. This investment behavior of firms may explain the low empirical responsiveness of investment to fundamentals.

Some papers, on the other hand, try to introduce nonlinearities in the investment process by modifying Q-theory models without excluding their simplifying assumptions. For example, Barnett and Sakellaris (1999) show that Tobin's Q, which is empirically measured with end-of-period average Q in their paper, is informative for investment once nonlinearity is allowed through new convex adjustment cost specifications such as higher-order convex costs. In this framework, their empirical specifications are based upon the linear homogeneity assumptions.

The basic problem in the second group of studies is that recent developments in the investment literature have started questioning the validity of the homogeneity assumptions on which Q-theory is founded. The first set of studies challenges the assumption of linear homogeneity of profit functions. They show that assumptions about constant returns to scale profit functions or perfectly competitive product markets may not be correct. Cooper and Haltiwanger (2003) at the plant level, Bayraktar (2002) at the firm level, Bayraktar, Sakellaris, and Vermeulen (2005) with German firm-level data, Cooper and Ejarque (2003a and 2003b) estimating a structural model show that the usual assumptions of linear homogeneity of profit functions may not be true. They find that the profitability parameter is less than 1 even though it is expected to equal 1 in case of constant returns to scale. This finding shows the existence of some monopoly power or decreasing returns to scale. In this case, as shown by Hayashi (1982), marginal Q differs from average Q. As a result, introduction of average Q as fundamental determinant of investment in empirical studies may lead to measurement errors.

The second set of recent studies indicates that linearly homogenous convex adjustment costs may not be sufficient to capture different types of costs in the investment process.[4] For example, Cooper and Haltiwanger (2003), Bayraktar (2002), and Bayraktar, Sakellaris, and Vermeulen (2005) study the presence of non-convex adjustment costs, and show that these types of costs are important in explaining firms' investment patterns as well. In this case, changes in capital adjustment costs may be high even though changes in capital are relatively small; thus, the linear homogeneity of the adjustment cost function may be misleading.[5] Estimated coefficients obtained from regressing investment on fundamentals may not give information on the structure of adjustment cost functions either.

In summary, two main results of these critics to the homogeneity assumptions are: 1) Average Q may not be a good approximation for marginal Q; and 2) it is doubtful to give structural adjustment cost interpretation to coefficients based on regressing investment on Q.

In light of these recent developments, the aim of this paper is to investigate whether a dynamic investment model based on more realistic assumptions such as firm market power and nonconvex adjustment costs can replicate the nonlinear relationship between investment and Tobin's Q. In this way, we hope to better understand the foundations of empirical results based on Q-theory investment models.

The focus is on one of the empirical specifications presented in Barnett and Sakellaris (1999). The structural model of their empirical specification is based on a linearly homogenous profit function and a higher-order linearly homogenous capital adjustment cost function. Their main findings from this model are much higher responsiveness of investment to Tobin's Q, and that

[4] The role of irreversibilities was stressed by Dixit and Pindyck (1994), Bertola and Caballero (1994), and Abel and Eberly (1996), among others. The role of fixed costs was stressed by Abel and Eberly (1994), Caballero and Leahy (1996), Caballero and Engel (1998), and Caballero and Engel (1999), among others.

[5] See Abel and Eberly (2002*b* and 2003).

the responsiveness of the investment rate to Tobin's Q gets higher as the value of Tobin's Q gets higher; thus, the responsiveness of investment is not proportional to the value of fundamentals.

Our goal is to reproduce the empirical results of Barnett and Sakellaris (1999) with the help of a structural model of investment which is not restricted by the standard homogeneity assumptions of neoclassical models. The model includes a fixed adjustment cost function and a decreasing returns to scale profit function as well as a quadratic convex adjustment cost.

The structural parameters of the model are estimated using an indirect inference method proposed by Gourieroux, Monfort and Renault (1993) and Smith (1993). This method involves choosing some regression coefficients or moments as benchmarks, which are taken in this paper from an empirical specification of Barnett and Sakellaris (1999). Then, we try to determine the structural parameters of the model in a way that the simulated data results match the actual benchmark results as close as possible.

The results are pending but the initial ones show the importance of both non-convex adjustment costs and market power in determining the nonlinear responsiveness of investment to Tobin's Q; thus, the structural model of Barnett and Sakellaris (1999) may be misspecified by not allowing for these features of firms.

In section 2 we develop a model of optimal investment behavior of a firm with market power, nonconvex and convex adjustment costs. Section 3 presents data related information, the initial empirical results and their evaluations. Section 4 concludes.

2 Structural Models

We present two models in this section. The first model is the investment model used by Barnett and Sakellaris (1999), which is based upon the Hayashi assumptions of constant returns to scale profit function and convex adjustment cost function. Then, an alternative model is presented, which allows for non-convexities in adjustment costs and firm market power.

2.1 Model and Empirical Specification in Barnett and Sakellaris (1999)

Their model is a neoclassical investment model with a higher-order convex adjustment cost function.[6] The purpose of the competitive firm manager is to maximize the present discounted value of the firm:

$$V(A_{it}, K_{it}) = \max_{I_{it}} \Pi(A_{it}, K_{it}) - C(K_{it}, I_{it}) + \beta E_{A_{it+1}|A_{it}} V(A_{it+1}, K_{it+1}), \quad (1)$$

subject to the following constraint:

$$I_{it} = K_{it+1} - (1 - \delta)K_{it},$$

where the subscripts i and t denote the firm level variables and time period, respectively. $V(\cdot)$ is the value function, $\beta E_{A_{it+1}|A_{it}} V(\cdot)$ is the present discounted future value of the firm, $C(\cdot)$ is the investment cost function, I_{it} stands for investment, K_{it} is the current capital stock, and δ is the depreciation rate. A_{it} is the profitability shock in period t. $\Pi(\cdot)$ is the profit function. β is the fixed discount factor.

[6] They introduce two new specifications of convex adjustment cost functions in their model. Both specifications produce similar results. The model here is presented with the higher-order convex cost function. We introduce additional simplifying assumptions such as the price of new investment is assumed to be constant even though it changes annually in Barnett and Sakellaris (1999).

It is assumed that both $C(\cdot)$ and $\Pi(\cdot)$ are homogenous of degree one in investment and capital. In this case, we can scale Equation (1) by K_{it}. If we divide both sides of Equation (1) by K_{it}:

$$v(A_{it}) = \max_{i_{it}} \ \pi(A_{it}) - c(i_{it}) + \beta(1 - \delta - i_{it})E_{A_{it+1}|A_{it}}v(A_{it+1}), \qquad (2)$$

where $i_{it} = I_{it}/K_{it}$, $v(A_{it}) = V(A_{it}, K_{it})/K_{it}$, $\pi(A_{it}) = \Pi(A_{it}, K_{it})/K_{it}$, $c(i_{it}) = C(K_{it}, I_{it})/K_{it}$, and $\beta(1-\delta-i_{it})E_{A_{it+1}|A_{it}}v(A_{it+1}) = \beta E_{A_{it+1}|A_{it}}V(A_{it+1}, K_{it+1})/K_{it}$.

Maximizing Equation (2) gives the following first order condition:

$$\frac{\partial c(\cdot)}{\partial i_{it}} = \beta E_{A_{it+1}|A_{it}}v(A_{it+1}).$$

In this equation, the investment rate is a function of expected future average Q, which is defined as $Q_{it+1} = V(A_{it+1}, K_{it+1})/K_{it+1}$.[7] Thus,

$$\frac{\partial c(\cdot)}{\partial i_{it}} = \beta E_{A_{it+1}|A_{it}}Q_{it+1} = \beta Q_{it+1} + \varepsilon_{it+1}, \qquad (3)$$

where ε_{it+1} is the error term.

In their model, Barnett and Sakellaris introduce the following higher-order convex adjustment cost function to explain the non-linear responsiveness of investment to fundamentals:

$$C(K_{it}, I_{it}) = pI_{it}+\gamma_1 I_{it}+\frac{\gamma_2}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it}+\frac{\gamma_3}{3}\left[\frac{I_{it}}{K_{it}}\right]^3 K_{it}+\frac{\gamma_4}{4}\left[\frac{I_{it}}{K_{it}}\right]^4 K_{it}+\mu_t I_{it}+\mu_i I_{it}, \qquad (4)$$

where p is the constant price of new investment. The μ_t and μ_i shocks allow for time and firm specific elements. If we divide both sides by K_{it},

$$c(i_{it}) = p.i_{it} + \gamma_1 i_{it} + \frac{\gamma_2}{2}i_{it}^2 + \frac{\gamma_3}{3}i_{it}^3 + \frac{\gamma_4}{4}i_{it}^4 + \mu_t i_{it} + \mu_i i_{it}.$$

After we take the derivative of $c(i_{it})$ with respect to i_{it}, Equation (3) becomes

$$\frac{\partial c(i_{it})}{\partial i_{it}} = p + \gamma_1 + \gamma_2 i_{it} + \gamma_3 i_{it}^2 + \gamma_4 i_{it}^3 + \mu_t + \mu_i = \beta Q_{it+1} + \varepsilon_{it+1}. \qquad (5)$$

[7] In neoclassical models, marginal and average Q are equal to each other thanks to the linear homogeneity assumptions. See Barnett and Sakellaris (1999) for details.

Using this first order condition, the empirical specification becomes

$$\beta Q_{it+1} = \gamma_1 + \gamma_2 i_{it} + \gamma_3 i_{it}^2 + \gamma_4 i_{it}^3 + p + \mu_t + \mu_i - \varepsilon_{it+1}. \tag{6}$$

In the empirical specification, they use the end-of-period average Q as a measure of Q_{it+1} since, as demonstrated by them, the beginning-of-period average Q cannot recover structural parameters related to the adjustment cost.[8] The estimated coefficients of Equation (6) give information about the convex adjustment cost function defined in Equation (4).

Their main results are that (1) the higher responsiveness of the investment rate to fundamentals,Q_{it+1}, compared to the results obtained in previous studies; and (2) the responsiveness of the investment rate is nonlinear.

All their empirical results are based upon the homogeneity assumptions which are questioned by some recent empirical studies as indicated in the introduction section. First, firms may have market power or decreasing returns to scale; thus, a constant returns to scale profit function is not a valid specification. Second, non-convex adjustment costs are important determinants of the non-linear responsiveness of investment to fundamentals; thus, a model ignoring this type of costs might be misspecified. In order to address these problems, an alternative model is presented in the following section.

2.2 Alternative Model

The alternative model introduces a non-convex adjustment cost function and a decreasing returns to scale profit function.[9] We model a monopolistically competitive firm. In the beginning of period t, firm i has real capital stock, K_{it}, which reflects all investment decisions up to the last period, and the firm

[8]Details about the calculation of Q_{it+1} are given in Barnett and Sakellaris (1999).

[9]The baseline model is the one presented by Cooper and Haltiwanger (2003). The main difference is that adjustment costs related to investment irreversibility are excluded in this paper.

also knows the current period profitability shock, A_{it}, which includes both aggregate and idiosyncratic profitability shocks. Given these state variables, the firm decides on the level of investment. The behavioral assumption is that firm managers maximize the firm's present discounted value.

2.2.1 Profits

The firm's operating profits are given in the following equation:

$$\Pi(A_{it}, K_{it}) = A_{it}K_{it}^{\theta}, \tag{7}$$

where $0 < \theta < 1$, reflecting the degree of monopoly power. A_{it} is the current period profitability shock. It may contain both an idiosyncratic component as well as an aggregate one.[10] The price of output is normalized to one. We also assume that capital is the only quasi-fixed factor of production, and all variable factors, such as labor and materials, have already been maximized out of the problem.

2.2.2 Adjustment Costs

The firm faces various costs when adjusting its capital stock. The model introduces both convex and non-convex adjustment costs.[11]

Convex costs

It is assumed that the convex adjustment cost is a quadratic function, which is common in the literature: $\frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it}$. The convex adjustment cost function implies that the investment rate is a linear function of fundamentals and it suggests continuous investment activity. Even though adjustment is

[10] The profitability shock is a function of technology, demand, wage, and materials cost shocks as well as structural parameters.

[11] The maintenance and gradual capital adjustments can be considered as examples of convex adjustment costs. Non-convex adjustment technology captures capital indivisibility, disruption costs caused by the installation of new capital, or training workers for the new capital; they lead to increasing returns to investment.

continuous, it is partial due to adjustment costs. The parameter γ determines the size of adjustment costs. The higher is γ, the higher is the marginal cost of investing and the lower is the responsiveness of investment to variations in fundamentals.

Fixed costs

The non-convex component of adjustment costs is introduced with fixed costs, which are assumed to be proportional to the capital stock: $F \times K_{it}$. The parameter F determines the magnitude of fixed costs, which is independent of the level of investment.

2.2.3 Value Maximization

The firm's dynamic program can be written as follows:

$$V^*(A_{it}, K_{it}) = \max \{V^a(A_{it}, K_{it}), V^{na}(A_{it}, K_{it})\}. \tag{8}$$

This equation indicates that the firm needs to choose optimally between buying or selling capital with value V^a, or not adjusting the capital stock at all with value V^{na}.

The value function of each one of these discrete choices $(j = a, na)$ is defined as follows:

$$V^j(A_{it}, K_{it}) = \max_{K_{it+1}} \Pi(A_{it}, K_{it}) - C^j(K_{it}, I_{it}) + \beta E_{A_{it+1}|A_{it}} V^*(A_{it+1}, K_{it+1}), \tag{9}$$

subject to the following constraint:

$$I_{it} = K_{it+1} - (1 - \delta)K_{it}, \tag{10}$$

where the subscripts i and t denote the firm level variables and time period, respectively. $V^*(\cdot)$ is the optimal value function, $\beta E_{A_{it+1}|A_{it}} V^*(\cdot)$ is the present discounted future value of the firm, $C^j(\cdot)$ is the investment cost function, where $j = na$ or a, I_{it} stands for investment, and δ is the depreciation rate. A_{it} is the profitability shock in period t. It contains both idiosyncratic shocks, ε_{it}, and aggregate shocks, a_t.[12] $\Pi(\cdot)$ is the profit function as defined in Equation (7). β is the fixed discount factor and equals $(1+r)^{-1}$ where r is the real interest rate.

The cost of investment, captured by $C(\cdot)$, depends on the choice of capital adjustment or not. In the case of capital adjustment, $j = a$, $C(\cdot)$ includes the purchase cost as well as fixed and convex adjustment costs:

$$C^a(K_{it}, I_{it}) = pI_{it} + \frac{\gamma}{2}\left[\frac{I_{it}}{K_{it}}\right]^2 K_{it} + FK_{it}, \tag{11}$$

where p is the constant price of new investment.

In case of no investment, $j = na$, the cost of investment is zero:

$$C^{na}(K_{it}, I_{it}) = 0. \tag{12}$$

In this framework, firms are going to have periods of inaction when fundamentals are not favorable, and large bursts of capital purchase or sale if fundamentals are high or low enough. The firm invests or disinvests when its capital stock is sufficiently more or less than its optimal level. Otherwise it prefers remaining inactive to avoid any fixed adjustment costs.

3 Empirical Results

3.1 Data Set

Since the aim of the paper is to reproduce the empirical results presented in Barnett and Sakellaris (1999), their data set is used in this study. The

[12] As is the case in Cooper and Haltiwanger's paper (2003), we assume that a_t is a first-order, two state Markov process with $a_t \in \{a_h, a_l\}$, where h and l denote high and low values of shocks. The idiosyncratic shocks take 11 different values and are also serially correlated. See Section 3.3 for details.

data set consists of firm level series taken from the NBER's COMPUSTAT releases.[13] After deleting some firms, Barnett and Sakellaris's data set ends up with the unbalanced panel of 1561 firms with 23207 observations, covering the period of 1960-1987. The gross investment is capital expenditures on property, plant, and equipment. The relative purchase price of capital, P_t, is taken as the ratio of the implicit price deflator for business-fixed investment over the implicit GDP deflator. The capital stock is net capital stock adjusted for inflation The distribution function of the investment rate is presented in Figure 1 for the period of 1960-87. Tobin's Q is equal to the ratio of the market value of firms to the replacement value of capital. The numerator is the sum of the market value of common stock, the liquidating value of preferred stock, the market value of long-term debt, and the book value of short-term debt. The denominator is the sum of the replacement value of fixed capital and inventories.

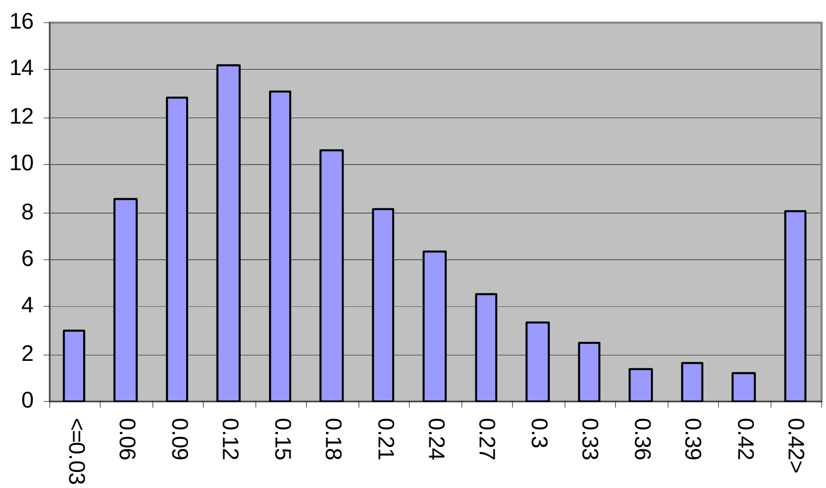

Figure 1: Distribution of the Investment Rate, 1960-1987

[13]Details on data set are given in Barnett and Sakellaris (1999) and Hall (1990).

Summary statistics are given in Table 1. The average value of the investment rate is 20 percent. The average value of end-of-period Q, Q_{it+1} is 1.68. The relative price of new investment is close to 1 on average. $\beta Q_{it+1} - P_t$ is the dependent variable of the regression Equation (6) as explained in the next section.

Table 2 reports the features of the distribution of the investment rate. The autocorrelation of investment rate is 0.31. It can be considered a large number when it is compared to the value found by Cooper and Haltiwanger (2003) using plant-level data, which was 0.007. The fraction of firms in the inaction region (the investment rate below 2.5 percent) is 2.03 percent. The investment rate is higher than 20 percent for 31.89 percent of observations. This number for the purpose of comparison was 18 percent in Cooper and Haltiwanger (2003).

Table 1. Summary Statistics (1960-87)

	mean	median	st.dev	25th percentile	75th percentile
I_{it}/K_{it}	0.20	0.15	0.24	0.09	0.23
Q_{it+1}	1.68	1.20	1.83	0.83	1.86
P_t	1.01	0.99	0.03	0.99	1.04
$\beta Q_{it+1} - P_t$	0.60	0.14	1.76	-0.22	0.77

Source: Table 1 on page 255, Barnett and Sakellaris (1999).

Table 2. Features of the Distribution of the Investment Rate

$\lvert I_{it}/K_{it}\rvert < 0.025$	2.03%
$I_{it}/K_{it} > 0.20$	31.89%
$\mathrm{corr}(I_{it}/K_{it}, I_{it-1}/K_{it-1})$	0.310

3.2 The Relationship between Investment and Tobin's Q

Barnett and Sakellaris (1999) show the nonlinear response of investment to changes in fundamentals (end-of-period average Q), using an empirical specification presented in equation (6). As indicated in the previous section, their empirical model is based on two assumptions: a higher-order convex adjustment cost function (equation (5)); and the firm does not have any market power, meaning that the profit function's slope parameter, θ, is equal to 1.

Since the aim of the paper is to investigate whether a dynamic investment model, which allows for firm market power and non-convex adjustment costs, could match the nonlinear responsiveness of investment to Tobin's Q, it would be appropriate to choose Barnett and Sakellaris's empirical specification as auxiliary regression. Thus, the following equation is used to determine the structural parameters of the model:[14]

$$\beta Q_{it+1} - P = \gamma_1 + \gamma_2 i_{it} + \gamma_3 i_{it}^2 + \gamma_4 i_{it}^3 + \mu_t + \mu_i - \varepsilon_{it+1}, \qquad (13)$$

where i_{it} is the investment rate at firm i in year t, which is defined as $\frac{I_{it}}{K_{it}}$. βQ_{it+1} is the present discounted value of end-of-period average Q, P is the relative price of new investment, μ_t captures the time specific effects, and μ_i captures the firm specific effects. It should be also pointed out that this regression equation's coefficients are responsive to changes in the structural parameters that we try to estimate; thus, they are informative in determining the structural parameters.

The coefficients of equation (13) are estimated with the data set introduced in Section 3.1. Table 3 shows the regression results, which match the

[14] As explained in the following sections, we use this equation as auxiliary equation to simulate the model with an indirect inference method.

estimated coefficients from Table 4 of Barnett and Sakellaris (1999), page 257. The regression method is ordinary least squares. A constant term, firm-level dummies and year dummies are also included, but not reported in the table.

Table 3: Auxiliary Regression

i_{it}	1.36* (0.07)
$(i_{it})^2$	-0.36* (0.04)
$(i_{it})^3$	0.023* (0.003)
Adjusted R-sq	0.65

Note: The dependent variable is $\beta Q_{it+1} - P_t$.
* significant at the 1% level.

3.3 Profitability Shocks and The Transition Matrix

The profitability shock, A_{it}, and its transition matrix is constructed using actual firm-level data series as defined in Section 3.1.

Profitability Shocks

In the model, the profitability shocks, A_{it}, represent the influence of demand and technology shocks. Our empirical strategy involves identifying these shocks directly in the data. First, we estimate the θ parameter of the profit function: $\Pi(A_{it}, K_{it}) = A_{it}K_{it}^{\theta}$. θ is the estimated coefficient obtained through regressing the natural log of net profit (net of cost of production) on the log of the replacement value of the capital stock using firm-level panel data.[15] The GMM AR(1) estimation technique calculates θ as 0.87.[16]

The profit shocks, A_{it}, are calculated following the way presented in Bayraktar, Sakellaris, and Vermeulen (2005). One way of calculating A_{it}

[15] θ is assumed to be the same for each firm in each period. However, if there are structural differences across firms, they need to be removed. Thus, we remove fixed effects to fix the structural heterogeneity problem.

[16] Details on calculating θ and profitability shocks are given in Bayraktar, Sakellaris, and Vermeulen (2006).

would be Π_{it}/K_{it}^{θ} from the profit function. But given that profit series are highly variable, an alternative way is used to calculate the profit shocks where profits are taken as a fixed factor times the wage bill. Thus, $\widehat{A_{it}/c} = w_{it}L_{it}/K_{it}^{\widehat{\theta}}$. where $\widehat{\theta}$ is estimated value of θ, $w_{it}L_{it}$ is wage bill, and c is $\Pi(A_{it}, K_{it})/w_{it}L_{it}$. First, $\widehat{A_{it}/c}$ is regressed on a constant and fixed firm effects to separate the fixed component and time varying component. Second, the residuals from the first regression are regressed on time dummies to identify the aggregate (a_t) and the idiosyncratic components (ε_{it}) of time varying component. The aggregate shocks are calculated using the estimated coefficients of time dummies, which are assumed to take a high and low value. These values are calculated using the Tauchen method (Tauchen, 1986) as $\{0.92,\ 1.08\}$. The serial correlation of the aggregate shocks is equal to 0.59. The idiosyncratic shocks take 11 different values, which are also serially correlated. The idiosyncratic shocks are presented in Table 4.

Table 4: Idiosyncratic Shocks

$\varepsilon 1$	$\varepsilon 2$	$\varepsilon 3$	$\varepsilon 4$	$\varepsilon 5$	$\varepsilon 6$	$\varepsilon 7$	$\varepsilon 8$	$\varepsilon 9$	$\varepsilon 10$	$\varepsilon 11$
0.59	0.79	0.86	0.91	0.96	1.00	1.05	1.10	1.17	1.28	1.63

The Transition Matrix of Idiosyncratic Shocks

The transition matrix of the idiosyncratic shocks is constructed using the residuals from the second regression given above. The transition matrix is presented in Table 5.

3.4 Structural Estimation

While simulating the model, we fix some of the structural parameters. The discount factor, β, equals $(1+r)^{-1}$ where r is the average nominal Baa corporate bond rate minus the measure of expected inflation from the Livingston Survey of twelve-month inflation expectations. The value of r is 0.05. In turn,

Table 5: Transition Matrix for Idiosyncratic Shocks

	$\varepsilon 1$	$\varepsilon 2$	$\varepsilon 3$	$\varepsilon 4$	$\varepsilon 5$	$\varepsilon 6$	$\varepsilon 7$	$\varepsilon 8$	$\varepsilon 9$	$\varepsilon 10$	$\varepsilon 11$
$\varepsilon 1$	0.61	0.19	0.08	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
$\varepsilon 2$	0.19	0.33	0.21	0.10	0.06	0.04	0.02	0.02	0.01	0.01	0.01
$\varepsilon 3$	0.07	0.20	0.25	0.20	0.12	0.06	0.04	0.02	0.02	0.01	0.00
$\varepsilon 4$	0.04	0.10	0.18	0.21	0.17	0.12	0.09	0.04	0.03	0.02	0.01
$\varepsilon 5$	0.03	0.06	0.11	0.17	0.18	0.18	0.12	0.07	0.04	0.02	0.01
$\varepsilon 6$	0.02	0.03	0.06	0.12	0.18	0.19	0.16	0.13	0.06	0.04	0.01
$\varepsilon 7$	0.01	0.02	0.04	0.07	0.13	0.17	0.19	0.19	0.11	0.04	0.01
$\varepsilon 8$	0.01	0.02	0.03	0.04	0.06	0.11	0.18	0.21	0.19	0.11	0.03
$\varepsilon 9$	0.01	0.02	0.02	0.03	0.05	0.08	0.11	0.19	0.26	0.19	0.05
$\varepsilon 10$	0.01	0.01	0.02	0.02	0.02	0.03	0.06	0.10	0.20	0.35	0.18
$\varepsilon 11$	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.04	0.07	0.20	0.60

β is approximately 0.95. The depreciation rate, δ, is equal to 0.06. This is the average value of the depreciation rate taken from the Bureau of Labor Statistics database prepared for 2-digit manufacturing firms by Rosenthal, Rosenblum, and Harper. The curvature of the profit function, θ, is calculated as 0.87 by regressing the log of real profit on the log of the real capital using firm-level data as described in the previous section. p is equal to 1.

Two structural parameters remain to estimate, $\Theta \equiv (\gamma, F)$, which are estimated using a numerical simulation method. Due to the presence of non-convex adjustment costs, which lead to discontinuity in the investment decision process, in turn, in the optimization problem, analytical methods cannot be used to solve the model. An indirect inference method, which is commonly used in the investment literature, is chosen to estimate the structural parameters.[17] The steps of this approach can be defined as follows.

[17] The one used in the paper is introduced by Gourieroux, and Monfort (1996), Gourieroux, Monfort and Renault (1993), and Smith (1993). The followings are some examples of empirical papers using this approach. Cooper and Haltiwanger (2003) estimate an investment model with both convex and non-convex adjustment costs. Adda and Cooper (2000) study the impact of scrapping subsidies on new car purchases. The distribution of price adjustment costs are estimated by Willis (1999). Cooper and Ejarque (2003a and 2003b) investigate the role of market power in the Q theory.

First, the firm's dynamic programming problem is solved for arbitrary values of the structural parameters, Θ, and the corresponding optimal policy functions are generated. The optimal policy functions are obtained using the value function iteration method, which works as follows: let υ be the value function. The value-function iteration starts with some initial υ_0 and then evaluates $\upsilon_{j+1} = T(\upsilon_j)$ for $j = 0, 1, 2, ...$ The desired value function is obtained when the difference between υ_{j+1} and υ_j is less than a predetermined threshold value.[18]

Second, simulated data are generated using these optimal policy functions and arbitrary initial conditions. In particular, we generate 8 artificial panels each containing data for 1000 firms for 25 years.[19]

Third, this simulated data set is used to calculate the model analogues of the auxiliary regression coefficients that are obtained using actual data. We choose to match the coefficients, γ_2 through γ_4, of the auxiliary regression Equation (13).

Fourth, we check whether the distance between Ψ^d, the vector of coefficients from the actual data, and $\Psi^s(\Theta)$, the vector of coefficients from data simulated given Θ, is arbitrarily close. If they are not, Θ is updated in a manner that is likely to make this distance smaller and go back to the first step.

More formally, we try to minimize the following quadratic function with respect to Θ:

$$\min_{\Theta} J(\Theta) = (\Psi^d - \Psi^s(\Theta))' W (\Psi^d - \Psi^s(\Theta)),$$

[18] Rust (1987*a* and 1987*b*) applied this method in his studies. Christiano (1990*a* and 1990*b*) showed that it performs better than linear-quadratic approximation in the context of the stochastic growth model.

[19] We drop the observations corresponding to initial periods in order to purge dependence on initial conditions.

where W is a weighting matrix.[20] In practice, we use the method of simulated annealing in order to minimize $J(\Theta)$.[21]

In their empirical specification, Barnett and Sakellaris (1999) use the end-of-period average Q as fundamental measure of investment. In the model, the end-of-period average Q is defined as

$$\beta Q_{it+1} = \frac{\beta E_{A_{it+1}|A_{it}} V^*(A_{it+1}, K_{it+1})}{pK_{it+1}}$$

where $\beta E_{A_{it+1}|A_{it}} V^*(A_{it+1}, K_{it+1})$ is the present discounted future value of the firm, K_{it+1} is the end-of-period capital stock, and p is the price of capital normalized to 1. In the model, the investment rate is defined as I_t/K_t.

3.5 Initial Results

We present the initial findings in this section. Table 6 reports the values of the estimated structural parameters, which produce the best results so far in terms of minimizing the distance between the actual coefficients from the regression equation (13) and the corresponding simulated coefficients.[22] The parameter γ, which has a value of 0.018, determines the magnitude of the convex adjustment costs. On the other hand, F determines the magnitude of the fixed adjustment costs, which is estimated as 0.13.

Table 6. Estimates of the Structural Parameters

Parameter	Estimate	Standard error
γ	0.018	
F	0.13	

[20] We use the inverse of the variance-covariance matrix of the estimated coefficients.

[21] There are a couple of advantages of this method compared to the conventional algorithms. First, this method explores the function's entire surface. Thus it is almost independent of starting values. The other advantage of this method is that it can escape from local optima. Further, the assumptions regarding functional forms are not strict. Goffe, Ferrier, and Rogers (1994) provide evidence that this algorithm is quite good in finding the global optimum for difficult functions.

[22] The calculation of the standard errors is pending.

Table 7 shows the estimated coefficients of the auxiliary regression equation calculated using actual and simulated data series, where the simulated data series are obtained using the structural parameters reported in Table 6. In general, the match is not good so far. But as indicated above, the simulation process is still in-progress. Thus, we expect to find a closer match.

Table 7. Auxiliary Regression Coefficients and Moments: Actual versus Simulated Data

Coefficient	Data	Std. error	Model	Std.error
i_{it}	1.36	(0.07)	0.582	(0.030)
$(i_{it})^2$	-0.36	(0.04)	0.403	(0.015)
$(i_{it})^3$	0.023	(0.003)	-0.040	(0.002)

The estimated values of γ in the empirical investment literature, especially the ones based on Q-theory, are much larger. For example, one of the lowest value of γ is calculated as 3 by Gilchrist and Himmelberg (1995). Cooper and Haltiwanger (2003) indicate that the high value of γ may be caused by the inclusion of only convex adjustment costs in the investment process. Thus, studies producing a high value of γ might be biased. But as the assumptions of investment models in terms of adjustment cost functions are relaxed, γ gets lower. Cooper and Haltiwanger (2003), who allow for market imperfections and non-convex adjustment costs in their model and use plant-level data, estimate γ as 0.049, which is higher than our estimated value but much lower than the values reported in other studies. Cooper and Ejarque (2003*a* and 2003*b*) estimate γ as 0.16. In the papers, they use firm-level data and introduce a decreasing returns to scale profit function but they do not include any non-convex adjustment costs. The estimated values of γ by Bayraktar (2002) and Bayraktar, Sakellaris, and Vermeulen (2005) are larger. While γ is 0.311 in the first paper, it is 0.532 in the second paper.[23]

[23] Bayraktar (2002) uses a model which combines non-convex adjustment costs with financial market imperfections and the data set from the COMPUSTAT database. The

Only a few papers, which estimate the structural parameter of the fixed cost function, are available. While the estimated value of F in this paper is 2.2 percent of the current capital stock as seen in Table 6. Cooper and Haltiwanger (2003) estimate F as 0.039, using plant-level data. The estimated value of F by Bayraktar (2002), using U.S. manufacturing firm-level data, is 2.9 percent. It is estimated as 3.1 percent by Bayraktar, Sakellaris, and Vermeulen (2005), using German manufacturing firm-level data.

The initial results show that while our estimate of γ is lower than previously estimated values, the estimate of F is larger when compared to previous estimates.

4 Conclusion

In this paper, we try to better understand the basis of empirical results based on Tobin's Q investment models. More specifically, we try to answer the question of whether conventional Q-theory is sufficient to explain the responsiveness of investment to average Q, and whether we can explain the nonlinear and significant responsiveness of investment to changes in average Q even in the absence of homogeneity assumptions of the conventional Q-theory. The results are pending but the initial ones indicate that market power and non-convex adjustment costs are important in determining the relationship between investment and average Q. Thus, the structural model of Q-theory might be misspecified by not allowing for firm market power or non-convexities in adjustment costs.

model by Bayraktar, Sakellaris, and Vermeulen (2005) tries to explain German firm-level investment, using a model introducing market power, different types of adjustment costs, and financial imperfections.

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