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Eleni Angelopoulou

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THE COMPARATIVE PERFORMANCE OF *Q*-TYPE AND DYNAMIC MODELS OF FIRM INVESTMENT: EMPIRICAL EVIDENCE FROM THE UK

Eleni Angelopoulou
Athens University of Economics and Business,
Bank of Greece

ABSTRACT

In this paper two models of investment stemming from the neoclassical theory are derived in a unifying framework. The *Q* type models view the stock market valuation of a firm as an all-encompassing variable determining its investment decisions, while the Euler equation for investment highlights the dynamic nature of firms' decision-making. A sample of 779 UK manufacturing companies listed in the London Stock Exchange in the period 1971-1990 is used to compare the empirical fit of the two different models of investment. Despite a number of difficulties, the *Q* model appears to be empirically superior delivering the desirable consistency between theory and data.

Keywords: Empirical investment models, Euler equation for investment, *Q* model
JEL classification: E22, C23, D92

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Correspondence:
Eleni Angelopoulou
Economic Research Department
Bank of Greece, 21 E. Venizelos Ave.,
10250 Athens, Greece,
Tel. +30 210 3203616
Fax: +30 210 3202163
e-mail: eangelopoulou@bankofgreece.gr

1. Introduction

Firm investment is an interesting decision to be made from both a microeconomic and a macroeconomic point of view. From a micro point of view it is interesting because firm investment in the present will influence the quantity of capital available in the future for the production process. But since it represents an outlay in the present, a balance has to be struck between the cost of investment today against the future profits expected from it. Hence, from a micro point of view investment can be formulated as a *dynamic optimization problem*, since it involves intertemporal allocation of resources.

From a macro point of view aggregate investment is important as a direct determinant of aggregate demand. Moreover, investment increases the productive capacity of the economy. Investment in capital is sensitive to interest rates since firms need to raise funds in order to finance their investment projects. Hence aggregate investment is sensitive to *monetary policy*. The *structure of capital markets* also plays an important role for investment, as it determines the availability of funds for the realisation of investment projects.

Starting from the formulation of a dynamic optimization problem, where a firm maximizes its intertemporal flow of revenues by choosing an appropriate investment path over time, three lines of research have prevailed in the empirical literature on firm investment. The first involves the identification of investment opportunities, captured by average *Q*, i.e. the ratio of market value of capital to its replacement cost (Hayashi, 1982). The second methodology consists in the derivation and estimation of an Euler equation, which highlights the intertemporal character of investment (Abel, 1980; Shapiro, 1986; Bond and Meghir, 1994). Finally, the third line of research involves a methodology for forecasting marginal revenue generated by new capital in the framework of a VAR model (Abel and Blanchard, 1986). This last method has been criticised on the grounds that it is subject to the Lucas' critique.

The variety of empirical work using *Q* models and Euler equations for investment highlights the advantages and shortcomings of the two approaches, but most importantly, it quite often leads to the finding that the behaviour implied by the neoclassical investment story is rejected for a given sample of firms or at least for sub-samples with certain characteristics (e.g. size, dividend policy, etc.) which could reveal financial constraints. Notwithstanding the technical shortcomings of some estimation methods, this failure is often attributed to financial market imperfections.

The Euler equation for investment is an alternative formulation of the solution to the neoclassical capital accumulation problem, but it is free from the empirical caveats of the Q model. First, it remains uncontaminated in case of measurement error or endogeneity of Q. Second, it is straight-forward to implement even in case of imperfect competition in output markets. Therefore an estimation of both empirical models using the same sample of firms for the same period of time would constitute a natural test for the validity of the neoclassical assumptions on which the two models are based. A bad empirical fit of both models could be an indication of invalidity of the neoclassical story. If, however, one of the two approaches appears to be superior, then failure of the other approach should not be necessarily taken as indication of invalidity of the neoclassical assumptions, but could be rather attributed to the particularities of the specific methodology.

This paper attempts a comparison of the empirical fit of the Q model and the Euler equation for investment on the basis of UK manufacturing data for the period 1971-1990. For this purpose the two models are derived in a unifying framework based on the firm's dynamic optimization problem (Part 2), so that analogies can be drawn. In Part 3 the data set and the empirical specifications are presented and results are reported, while Part 4 concludes.

2. Firm investment: A unifying analytical framework

Theoretical models of investment evolved in the last fifty years basically due to the need to rationalize the prevalent empirical models and their findings in a theoretically appealing framework. One of the earliest versions of empirical investment models was the accelerator model, which explained investment on the basis of current and lagged changes of sales growth. Although this type of model did not perform badly in fitting the data, it lacked a convincing theoretical background. The neoclassical investment theory views investment as a choice variable for managers, whose objective is to maximize the firm's value for its shareholders. The first version of the neoclassical model developed by Jorgenson (1963) assumed a CRS technology producing an exogenously given amount of output and used an *ad hoc* rule for investment evolution to tie down the investment rate. The result is a specification in which the investment rate is determined by the user cost of capital.[1] Despite the simplicity and intuitiveness of this specification, empirical models using aggregate investment data failed to deliver evidence of its validity in practice.

The late versions of the neoclassical investment model use convex installation costs of new capital to deliver a *q*[2] model of investment (Lucas, 1967; Gould, 1968; Uzawa, 1969; Treadway, 1969). Marginal *q* is defined as the ratio of the marginal revenue product of an additional unit of capital to the marginal cost of its installation and it was viewed at that time as an all-encompassing variable which summarizes firms' investment opportunities (controlling also for changes in the user cost of capital) and determines their investment rates. When *q* is larger than 1, i.e. when the marginal capital unit adds to a firm's value more than its cost, then it is profitable for the firm to install new capital and hence investment increases. The opposite happens when *q* is less than 1, while $q=1$ means that the firm will be indifferent between undertaking an investment project or not.

One problem associated with the empirical estimation of *q* models which was identified early on in the literature, is that marginal *q* is unobservable to the econometrician. Hayashi (1982) showed that under a number of additional assumptions (perfect competition in the product market and linear homogeneity of the production and adjustment cost functions) marginal *q* is equal to average *Q*, where average *Q* is the market value of the firm divided by the replacement cost of installed capital. In contrast to marginal *q*, average *Q* can be constructed from stock market data[3] and hence an investment model based on average *Q* can be estimated in practice.

The empirical relevance of average *Q* for investment is however not undisputed. On the contrary, the assumption of perfect competition in product markets is obviously questionable, although there are ways to keep the main framework intact

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[1] The user cost of capital is the return required by firms in order to undertake an investment, gross of depreciation (see Bond and Jenkinson, 1996).

[2] A notational distinction should be made between small *q,* referring to marginal *q*, i.e. the *additional* value generated for the firm by the marginal unit of capital relative to its cost, and large *Q*, which refers to average *Q*, i.e. the ratio of the market value of a firm to the replacement cost of its capital.

[3] For another approach of estimating marginal *q* on the basis of a VAR model, see Abel and Blanchard (1986). Their results confirm the main findings of the average *Q* empirical literature, thus supporting the view that measurement errors or endogeneity biases are not the main driving forces of the results. However, as already mentioned their methodology has been criticized as being subject to the Lucas' critique.

even without this assumption,[4] but additional issues regarding the correct valuation of a firm's assets in stock markets in the presence of information asymmetries and even the incentives of managers to maximize the firm's value are questioned in the literature. Also, two technical problems could arise regarding average *Q*. The first is a measurement error in observed *Q* which could lead to biased (downwards) and inconsistent estimates in a regression of the investment rate on *Q*. A measurement error can result from a discrepancy between marginal and average *Q* (due to output market imperfections), or between average *Q* and Tobin's *q* (due to information asymmetries in the capital markets), but it can also arise from the construction of the replacement cost of capital series. As has been shown by Griliches and Hausman (1986), under certain assumptions regarding the process of the measurement error, this problem can be addressed by implementing an IV approach with lagged values of *Q* used as instruments.[5] Fazzari, Hubbard and Petersen (1988) just estimate the model in first differences, although Griliches and Hausman (1986) show that this could exacerbate the measurement bias. A second problem which might arise is endogeneity of *Q*. Since marginal *q* is the present value of current and future profits arising from the marginal unit of capital, a positive shock to the adjustment cost function at time *t* will affect investment directly but also by increasing *q* due to the increase in expected future profitability. However, also this problem can be dealt with by using an appropriate GMM procedure for the estimation of the investment equation. For example Hayashi and Inoue (1991) achieve identification under the assumption of specific stochastic properties for the error term in the investment equation, by applying a GMM procedure where leads and lags of investment, *Q* and cash-flows are used as instruments.

Apart from the construction and the stochastic properties of *Q*, investment models based on it lead to puzzling results when cash-flow terms are added. It has been a common finding across a number of studies that cash-flow has a statistically

[4] If the perfect competition in the product market assumption is dropped, then average *Q* will be higher than marginal *q* and the wedge between them equals the monopoly rent (Hayashi, 1982). For an empirical application on UK data see Schiantarelli and Georgoutsos (1990).

[5] For a different treatment of measurement error in *Q* see Erickson and Whited (2000). They apply a GMM procedure exploiting information included in higher than second order moments of the observed variables, derive an overidentified system and then obtain the *J*-test of overidentifying restrictions to test for departures from the assumptions necessary for the consistency of their estimators. Their results imply that measurement error can explain the low explanatory power, the high adjustment costs and the statistical significance of other variables like cash-flows, which are frequently found in the empirical literature on *Q* models of investment.

significant positive effect when added to *Q* models of investment. There are three alternative interpretations in the literature for this finding. The first points out that cash-flow is closely correlated with profits and sales and hence it adds more information on firm profitability and investment opportunities in a *Q* model, especially if observed *Q* displays a measurement error. Furthermore in the case of a firm which has monopoly power in the market for the good it produces, the marginal revenue of capital is not just equal to the average profit of installed capital, but is augmented by an additional output term scaled by the elasticity of demand (Hayashi, 1982). In this case the statistical significance of cash-flow in a *Q* model could be an indication of imperfect competition in the goods market. Fazzari, Hubbard and Petersen (1988) find that the statistical significance of the coefficient on cash-flow persists even after controlling for output by including a lagged sales-to-capital term. As will be shown in the next section however, the treatment of imperfect competition in the framework of the *Q* model is more complicated.

An alternative explanation put forward for the significance of cash-flow is that sometimes managers use free cash-flow (cash-flow left after investment in profitable projects has been realised) to overinvest, i.e. that they engage in suboptimal investment policies, in which case the *Q* model is not an appropriate description of firm investment behavior (see Jensen, 1986). It could also be the case that managers engage in suboptimal financing strategies for profitable investment projects, e.g. that they show a preference for internal funds rather than external financing contracts which could make them subject to restrictive covenants and scrutiny. This free cash-flow story could provide an interpretation for the statistical significance of cash-flow in *Q* models of investment. However, it is very difficult to test as free cash-flow cannot be observed.

The third and dominant interpretation in the literature is that the empirical significance of cash-flow terms in *Q* specifications reflects the existence of financing hierarchies associated with financial market imperfections. According to this argument, the explanatory power of cash-flow can be attributed to the fact that it is a proxy for the firm's net worth and as such it determines the external finance premium facing the firm (see e.g. Fazzari, Hubbard and Petersen, 1988; Chirinko and Schaller, 1995). Hence, despite the theoretical appeal of *Q* as a measure of investment opportunities, the empirical application in the estimation of investment models failed to establish it as the undisputed determinant of firm investment behavior.

To circumvent some of the empirical caveats of *Q* models, an alternative methodology has been developed to derive an Euler equation for investment in the neoclassical framework. Again, with the assumption of convex installation costs and linear homogeneity of the production and adjustment cost functions one can derive a specification in which the investment rate is determined by linear and quadratic terms of the lagged investment rate, as well as lags of cash-flow and the cost of capital.[6] One important advantage of the Euler equation approach is that it does not rely on the construction of a summary measure like average *Q*. Hence, it can be estimated even for companies which are not quoted on a stock market and its validity cannot be questioned on the basis of measurement errors or endogeneity of the regressors. Among its potential pitfalls however is the fact that the role of various determinants of investment (e.g. in capturing investment opportunities, availability of finance, management incentives etc.) is obscured. Moreover, Mairesse (1994) has shown that Euler equations for investment demonstrate parameter instability, which could again be blamed on capital market imperfections, but could in fact be associated with a more general specification problem. Finally, the fact that it rests largely on the same assumptions as the *Q* model, especially regarding perfect financial markets and management incentives to maximize firm value (instead of e.g. firm size to gain personal power), renders it subject to the earlier mentioned relevant criticism.

Given the dominance of the neoclassical investment theory, the empirical literature on investment has mainly focused on (variants of) the *Q* model and the Euler equation of investment. There are a number of studies published using data for various developed and developing countries (see e.g. Bond and Meghir, 1994, for the UK; Fazzari, Hubbard and Petersen, 1988, for the US; Hayashi and Inoue, 1991, for Japan; Athey and Laumas, 1994, for India; Cho, 1995, for Korea; Bond, Elston, Mairesse and Mulkay, 1995, for France, Belgium, Germany and the UK). Although the bulk of studies focuses on manufacturing, both because of its important role for aggregate output and employment and because of data availability, there are a few studies from other sectors or specific type of firms, covering e.g. agriculture (Hubbard and Kashyap, 1992), high-tech industry (Himmelberg and Petersen, 1994) and hospital services (Calem and Rizzo, 1995). Moreover, different types of investment expenditure have been studied, like inventory investment (Carpenter, Fazzari and

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[6] If the firm is assumed to have some monopoly power in the output market, an additional output term will be included in the Euler equation for investment (see section 2.2).

Petersen, 1994), R&D expenditure (Hall, 1992), investment in equipment (DeLong and Summers, 1991), labour demand (Nickell and Nicolitsas, 1995) and investment in market share under imperfect competition (Phillips, 1995), although again the bulk of evidence relates to business fixed investment in general (plants, buildings and equipment).

2.1 Investment behavior of an optimizing firm under perfect competition

At each point in time a representative firm[7] maximizes its value, which is a function of the previous period stock of capital. The firm cannot control the stock of capital available to it in each period, but it can influence the pattern of capital accumulation by appropriately choosing an investment rate. Hence the firm's problem can be summarized as follows:

$$V_t(K_{t-1}) = \max_{\{I_s\}_{s=t}^{\infty}} \left\{ R(K_t, L_t, I_t) + \beta E_t \left[V_{t+1}(K_t) \right] \right\}, \tag{1}$$

where $V_t(K_{t-1})$ is the firm's current period value function, β is a discount factor, E_t is the expectations operator based on the time t information set, and $R(K_t, L_t, I_t)$ is the net revenue, given by:

$$R(K_t, L_t, I_t) = p_t F(K_t, L_t) - p_t C(K_t, I_t) - w_t L_t - p_t^I I_t \tag{2}$$

In expression (2) $F(.)$ is a production function and $C(.)$ is a cost-of-adjustment function. K, L and I stand for capital, labour and investment, respectively,[8] w_t is the wage rate, p_t is the price of the firm's product and p_t^I is the price of investment goods. The subscript t denotes time. The revenue function can easily become stochastic if a technology shock in the production function or in the cost-of-adjustment function is allowed for. A positive shock would increase net output and, given prices, it would also increase firm revenue. The representation of the firm's problem as in equation (1) reduces an optimization problem with an infinite horizon to the equivalent two-period problem. At the beginning of the period the firm chooses an investment rate, so that new capital is installed, which becomes operative immediately. Capital formation follows the rule:

[7] The representative firm assumption enables us to drop the *i* subscript for firm in this and the following section. We assume a unique capital input. For a model with multiple capital goods, see Hayashi and Inoue, 1991.
[8] Capital and labour are assumed to be the only inputs to production.

$$K_t = (1-\delta)K_{t-1} + I_t \tag{3}$$

with δ denoting a constant depreciation rate. The firm faces convex installation costs increasing in investment, i.e. the higher the investment in proportion to existing capital the higher the costs in terms of lost output. This can be thought of as implying that a big investment project causes a relatively larger disruption in production (time and cost associated with the installation of new machinery, training workers etc.) than a small project. Adjustment costs are given by the cost-of-adjustment function, $C(K_t, I_t)$. We assume that both the production function, $F(K_t, L_t)$, and the cost-of-adjustment function are homogeneously linear in capital. In order to be able to derive an expression for the investment rate, we need to specify a functional form for the cost of adjustment function. The most common form in the literature is the quadratic, given by:

$$C(K_t, I_t) = \frac{1}{2} a K_t \left[\left(\frac{I}{K} \right)_t - b \right]^2 \tag{4}$$

Under perfect competition the first order conditions for the firm's maximization problem[9] with respect to previous period capital stock give:

$$\frac{\partial L(K_t, L_t, I_t)}{\partial K_{t-1}} = (1-\delta)\left(\frac{\partial R_t}{\partial K_t} \right) + \beta(1-\delta)E_t \frac{\partial V_{t+1}(K_t)}{\partial K_t} - \lambda_t (1-\delta) = 0 \tag{5}$$

We can rewrite equation (5) as follows:

$$\left(\frac{\partial R_t}{\partial K_t} \right) + \beta E_t \frac{\partial V_{t+1}(K_t)}{\partial K_t} = \lambda_t \tag{5'}$$

Equation (5') has a straight forward economic interpretation. It states that the shadow value of capital, i.e. the additional value for the firm from relaxing constraint (3), is equal to the discounted value of current and future revenues generated by the marginal unit of capital. The first order condition with respect to investment then gives:

[9] The firm maximizes its value function subject to the capital formation constraint (3), so that the Langrangean corresponding to the firm's problem as we formulated it here is:

$$L_t = R(K_t, L_t, I_t) + \beta E_t \left[V_{t+1}(K_t) \right] + \lambda_t \left[K_t - (1-\delta)K_{t-1} - I_t \right]$$

$$\frac{\partial L(K_t, L_t, I_t)}{\partial I_t} = \frac{\partial R_t}{\partial I_t} - \lambda_t = 0 \quad (6)$$

As has been pointed out previously the literature on investment has used the first order conditions of this optimization problem to derive an expression for investment in various fashions. One way to go from here is to use (6) to derive an investment equation based on average *Q* [Hayashi (1982)]. Another way would be to combine (5') and (6) to derive the Euler equation for investment [Bond and Meghir (1994)].

2.1.1 A Q model of investment

We can use (6) to solve for the optimal investment rate $\left(\frac{I}{K}\right)_t$:

$$\left(\frac{I}{K}\right)_t = b + \frac{1}{a}\left(\frac{\lambda_t}{p_t^I} - 1\right)\frac{p_t^I}{p_t} + \varepsilon_t \quad (7)$$

Using the fact that λ_t / p_t^I is marginal *q*, i.e. the market value added to the firm by the marginal unit of capital divided by its replacement cost, we can rewrite (7) as:

$$\left(\frac{I}{K}\right)_t = b + \frac{1}{a}(q_t - 1)\frac{p_t^I}{p_t} + \varepsilon_t \quad (7')$$

ε_t can be thought of as an optimization error. An additive shock to the cost-of-adjustment function would also have the same effect. Expression (7') links the investment rate to marginal *q* adjusted for the relative price of investment goods. Under the assumptions that the production function is linearly homogeneous in capital and labour, the cost function is linearly homogeneous in capital and investment and output markets are perfectly competitive, Hayashi (1982) has shown that marginal *q* is equal to average *Q*, i.e. the market value of the firm as a ratio of the replacement cost of installed capital, which is observable to the econometrician. Hence, equation (7') can be used to estimate the investment rate of an optimizing firm under perfect competition.

2.1.2 A dynamic model of investment

An alternative way to proceed would be to use the fact that $E_t \frac{\partial V_{t+1}(K_t)}{\partial K_t} = (1-\delta) E_t \lambda_{t+1}$,[10] to rewrite (5') as follows:

$$\left(\frac{\partial R_t}{\partial K_t}\right) + \beta(1-\delta) E_t \lambda_{t+1} = \lambda_t$$

Now using (6) to substitute out λ we derive the Euler equation for investment:

$$\left(\frac{\partial R_t}{\partial K_t}\right) - \left(\frac{\partial R_t}{\partial I_t}\right) = -\beta(1-\delta) E_t \left(\frac{\partial R_{t+1}}{\partial I_{t+1}}\right) \tag{8}$$

Equation (8) states that the net revenue generated by the marginal unit of capital at time t should equal the discounted value of marginal expenses for investment at time $t+1$, so that the firm becomes indifferent between investment in two adjacent periods. If net revenue from the installation of an additional unit of capital at time t exceeded marginal expenses for investment at time $t+1$, the firm would invest more in time t and vice versa. In this sense, solving equation (8) for $\left(\frac{I}{K}\right)_{t+1}$ will give the optimal (intertemporally) rate of investment. Given the specific functional form of the cost-of-adjustment function this is:[11]

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[10] This follows from the fact that $(1-\delta)\left(\frac{\partial R_t}{\partial K_t}\right) + \beta(1-\delta) E_t \frac{\partial V_{t+1}(K_t)}{\partial K_t} = \frac{\partial V_t(K_{t-1})}{\partial K_{t-1}}$ (from (1)), and hence (using (5)) $\frac{\partial V_t(K_{t-1})}{\partial K_{t-1}} = \lambda_t (1-\delta)$.

[11] Note that perfect foresight is needed to drop the expectations operator. To derive the expression for $\frac{\partial R_t}{\partial K_t}$ we used linear homogeneity of the production function in capital and labour to write $\frac{\partial F(K_t, L_t)}{\partial K_t} = \frac{F(K_t, L_t)}{K_t} - \frac{\partial F(K_t, L_t)}{\partial L_t}\frac{L_t}{K_t} = \frac{p_t Y_t - w_t L_t}{p_t K_t} = \left(\frac{CF}{K}\right)_t$, i.e. the marginal product of capital is equal to cash-flow as a rate of capital stock. Therefore, under the assumption of a CRS production function the ratio of cash-flow to capital stock is equal to the marginal product of capital.

$$\left(\frac{I}{K}\right)_{t+1} = \left(\frac{b^2}{2} - b\right)\varphi_{t+1} + b + \varphi_{t+1}\left(\frac{I}{K}\right)_t - \frac{\varphi_{t+1}}{2}\left(\frac{I}{K}\right)_t^2 - \frac{\varphi_{t+1}}{a}\left[\left(\frac{CF}{K}\right)_t - J_{t+1}\right] + u_{t+1} \quad (9)$$

where u_{t+1} is again an optimization error.

Here $\varphi_{t+1} = \frac{1 + i_{t+1}^e}{(1 + \pi_{t+1}^e)(1 - \delta)}$ is the real discount factor, adjusted for depreciation (i_t and π_t stand for nominal interest rate and inflation rate, respectively, and *e* denotes expectation) and J_{t+1} is the cost of capital given by the expression $J_{t+1} = E_t\left(\frac{p_{t+1}^I}{p_{t+1}}\frac{1}{\phi_{t+1}}\right) - \frac{p_t^I}{p_t}$. This expression shows that the cost of capital is equal to the expectation of the discounted relative price of net investment tomorrow minus the relative price of investment goods today. It should be noted that the cost of capital and the cash-flow term enter equation (9) with equal and opposite coefficients. Under the assumptions made above, this means that the investment rate actually depends negatively on the difference between the marginal product of capital at time *t* and the increase in the relative price of investment between periods *t* and *t+1*. This term can be thought of as capturing the opportunity cost of investment at time *t+1*.

2.2 Investment behavior of an optimizing firm with monopoly power

If the firm has monopoly power in the market for the good it produces, then the above conditions have to be altered to take account of the fact that additional units of capital will increase the scale of production and the monopoly rent which accrues to the firm. It is useful to formulate the revenue function as:

$$R_t = p_t F(K_t, L_t) - p_t C(K_t, I_t) - w_t L_t - p_t^I I_t = p_t Y_t - w_t L_t - p_t^I I_t$$

where $Y_t = F(K_t, L_t) - C(I_t, K_t)$ is net output. If we denote by η the elasticity of demand for net output produced by the firm and let $c = 1 + 1/\eta$, then it can be easily shown that in the case of a firm with monopoly power in the output market the equivalent of expression (7') for investment becomes:

$$\left(\frac{I}{K}\right)_t = b + \frac{1}{ac}(q_t - 1)\frac{p_t^I}{p_t} + \varepsilon_t \quad (10)$$

Since c is a positive scalar lower than one, the coefficient on the marginal q term is higher in this case, compared to the perfect competition version of the model, indicating a larger responsiveness of investment to the market valuation of the firm, when the latter has monopoly power. However, equation (10) cannot be used for the estimation of an investment equation under monopoly power. The reason is that the equality between marginal q and average Q breaks down. As has been shown by Hayashi (1982), average Q in this case equals marginal q plus the monopoly rent. The latter can be shown to be equal to the discounted present value of current and future sales-to-capital ratios, scaled by c. Simply substituting the market-based average Q for marginal q would lead then to measurement error. On the other hand, since it is difficult to find a proxy for future monopoly rents average Q cannot be accordingly adjusted and therefore the Q model would give downward biased coefficient estimates.[12]

Compared to the Q model, the dynamic model of investment allows for a straightforward handling of market power. In a similar way it can be shown that the investment specification resulting from the Euler equation can be written in the case of monopoly power as:

$$\left(\frac{I}{K}\right)_{t+1} = \left(\frac{b^2}{2} - b\right)\varphi_{t+1} + b + \varphi_{t+1}\left(\frac{I}{K}\right)_t - \frac{\varphi_{t+1}}{2}\left(\frac{I}{K}\right)_t^2 - \frac{\varphi_{t+1}}{ac}\left[\left(\frac{CF}{K}\right)_t - J_t\right] + \frac{(1-c)\varphi_{t+1}}{ac}\left(\frac{Y}{K}\right)_t + u_{t+1} \quad (11)$$

In this specification not only the coefficient on cash-flow and on the cost of capital is scaled by c but also a positive output term appears in the Euler equation. In the case of perfect competition $c = 1$ and this term disappears, so that this specification collapses back into (9).

3. Data and empirical evidence

In this section we make an attempt to explain the investment behaviour of British manufacturing firms in the 1970s and the 1980s by estimating both a Q-based and a dynamic model of investment, using the analytical framework discussed in the previous section.

[12] Schiantarelli and Georgoutsos (1990) propose a way to circumvent the problem of monopoly power in the framework of a Q model. They quasidifference the investment equation, so that the part of the sales term which depends on expected future sales disappears. They construct a modified Q including this term in the numerator and run a regression of investment on modified Q and sales.

We use panel data for 779 British[13] manufacturing firms quoted on the London Stock Exchange over the period 1971-1990. The two databases from which the data stem are the EXSTAT[14] database compiled by Extel Financial Limited, which contains balance sheets and profit and loss accounts, and the London Share Price Database to match the firm-level data with stock market information. Some general descriptive characteristics of the sample are included in Table 1. The sample has been divided into three size groups.[15] In order to construct the size groups, first the average (across time) size of a firm is computed on the basis of its in-sample information on deflated net assets. Then, the boundaries between the groups are defined by the 33rd and the 66th percentile of the average size distribution of firms. Observations are more or less equally distributed among size classes with a small bias towards the upper size group. In fact more companies are included in the small size group, but the average number of records per company increases with company size with 12.6 years for small companies, 13.8 years for middle and 16.5 years for large companies.

The descriptive summary of our sample in Table 1, reveals that the average size of firms in the upper size group is about 90 times bigger than that in the lower group. Also, average sales growth (sales growth is an important determinant of investment in accelerator models) as well as average investment rate, defined as the ratio of new investment to existing capital stock at the end of the previous period, is higher for small firms. Regarding their financial policies, small firms resort more heavily than large ones to bank finance. Small firms also appear to rely more on retentions than large firms, even paying zero dividends in 16.4% of the available sample observations compared to a rather low 4.4% for large firms. This is also supported by the fact that the ratio of the total cost of equity dividends to the profits available for dividends is higher for large firms.

It should be noted that normally accounting period practices vary across companies and across time. In order for flow data to be comparable these are therefore scaled by a factor which equals one for 12-month or 52-week accounting periods and is accordingly adjusted for smaller or larger accounting period durations. This

[13] A few Irish and Dutch manufacturing firms listed on the LSE are also included, with their balance sheet and profit and loss account items being converted into UK pounds using average annual exchange rates.
[14] For antother use of the EXSTAT database see Dickerson, Gibson and Tsakalotos (2002).
[15] For a detailed definition of variables, see Appendix.

essentially entails the simplification that flow variables evolve linearly during a year. The benefits of this approach seem, however, larger than its potential drawbacks, since it allows the use of a much larger number of company data.

In this paper only investment in property and other tangible assets is considered. The replacement cost of such assets might differ significantly from their historical cost reported in the balance sheet due to reasons such as depreciation, factor price inflation and technological progress. In particular, depreciation and technological progress tend to decrease the value of installed capital goods, whereas factor price inflation tends to increase it. For the calculation of the replacement cost of assets the perpetual inventory formula was used:

$$K_t^R = \pi_t K_{t-1}^R + (K_t^B - K_{t-1}^B)$$

where π_t is a deflator, defined below, K^R denotes replacement cost and K^B denotes historical cost of assets.

Table 1: The profile of the sample

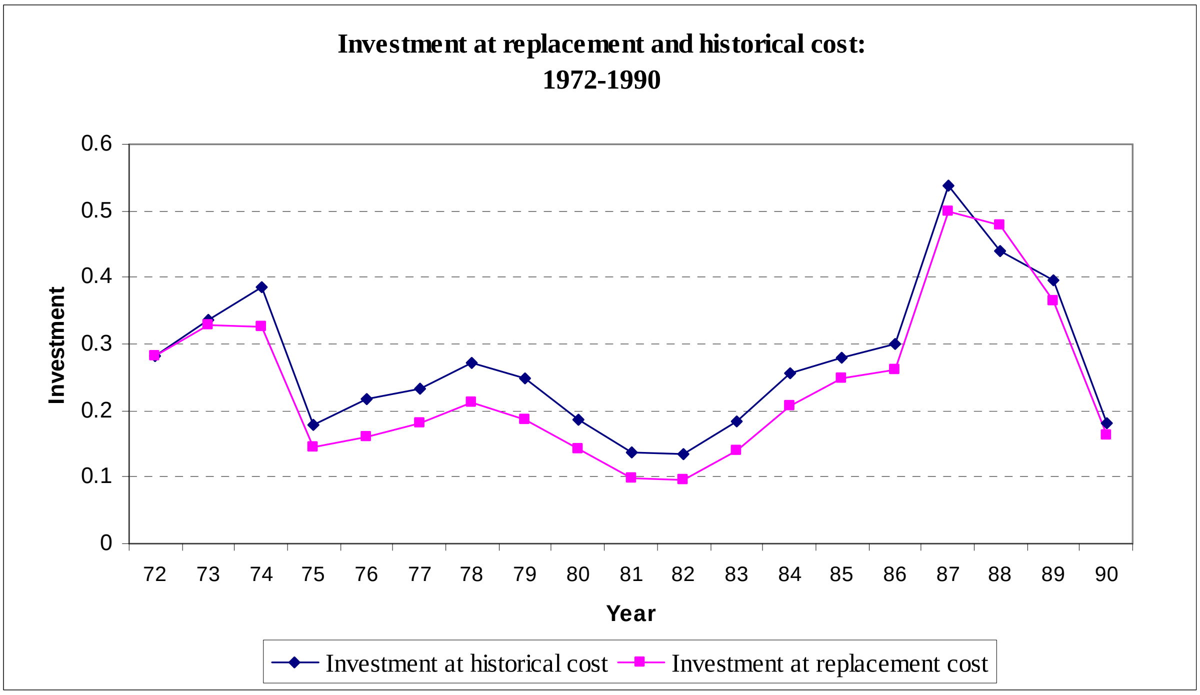
	Size class		
	1 Lower (33rd percentile)	2 Middle (66th percentile)	3 Upper (100th percentile)
General characteristics			
Number of companies	289	264	226
Number of observations	3645	3637	3740
Average years/company	12.6	13.8	16.5
Average size (deflated net assets)	£3,5 million	£13,5 million	£315 million
Average sales growth per year	19.1%	16.9%	18.1%
Average investment rate	25.6%	22.8%	19.6%
Finance			
Bank loans (% of total assets)	40.7%	29.8%	20.4%
Retained earnings (% of available profits)	67.4%	55.7%	53.3%
Dividend policy			
Percentage of years with zero dividend payouts (gross)	16.4%	7.6%	4.4%
Total cost of equity dividends/profits available for dividends	30.6%	43.2%	45.1%

This states that the replacement cost of capital at time *t* is equal to the replacement cost of capital at period *t-1*, appropriately deflated, plus the change in the historical cost of capital (i.e. investment) between time *t-1* and time *t*. For the first time period it is necessary to assume that the replacement cost of assets equals the historical cost. Of course, as one moves further away from the base period, this assumption carries less weight. Moreover, this assumption allows us to calculate a series of replacement costs, which is an improvement compared to using the historical cost series. A number of additional assumptions are needed for the calculation of the deflator. We assume here that the deflator is given by the formula:

$$\pi_t = \frac{\left(1+\pi_t^F\right)(1-\delta)}{(1+\theta)}$$

where π_t^F is the gross fixed capital formation deflator, δ is the depreciation rate, assumed to be 2.5% for land and buildings and 8.19% for plant and machinery,[16] and θ is the rate of technological progress. For lack of data, this latter term is ignored and time-varying technology shocks are captured by the inclusion of time dummies below.

Chart 1



For the construction of the investment rate series which is used as regressand below the difference in total fixed assets (gross of depreciation) between periods *t* and *t-1* is divided by the replacement cost of capital at the end of period *t-1* (see Chart 1). The series of investment divided by capital stock at historical cost is also shown in

[16] According to calculations by King and Fullerton (1984) for UK manufacturing.

Chart 1, and it can be seen to be slightly lower than the one at replacement cost (as capital stock at replacement cost, i.e. the denominator, is higher), but in general the correlation between the two series is very high.

Since one of the equations to be estimated uses average *Q* as a regressor, the construction of this variable is crucial. It should be noted that the average *Q* used as a regressor in the following section is not tax-adjusted. To calculate a tax adjusted series, information on the corporate tax rate, the investment tax credit and the present value of depreciation allowances due to past investment must be available. Since the capital stock measure used here also does not take account of tax considerations, ignoring taxes should not matter for the qualitative comparison between the *Q* model and the Euler equation. However, because of the use of tax-unadjusted *Q*, the reader should be cautioned against a structural interpretation of the parameters in the *Q* estimations in the following section.

First, stock market information is required to calculate a firm's market value. In particular the market value of a company is assumed to equal the market value of its shares plus the value of its debt. The average market value of the company's shares over a year can be defined as the product of its average share number multiplied by the mean transaction price at which the company's shares were traded during the year. Given data limitations, the average number of shares is calculated simply as the mean of the number of shares in period t and period $t+1$ (as a result *Q* cannot be calculated for the last sample period of each company). Average *Q* is then derived by dividing the sum of the market value of the firm plus its debt[17] by the replacement cost of existing capital stock at the end of the previous period. We also calculate average *Q* dividing by the historical cost of fixed assets. However, the two alternative measures of *Q* are highly correlated with each other as they are both driven by market trends. Both series are presented in Chart 2. Finally, to give an idea of the relationship between *Q* and investment rate at replacement cost, the two series are plotted together in Chart 3.

[17] The value of a firm's debt is added to its average market value to take account of the possibility that debt can be used as an additional source of finance (beside internal finance and issue of equity).

Chart 2

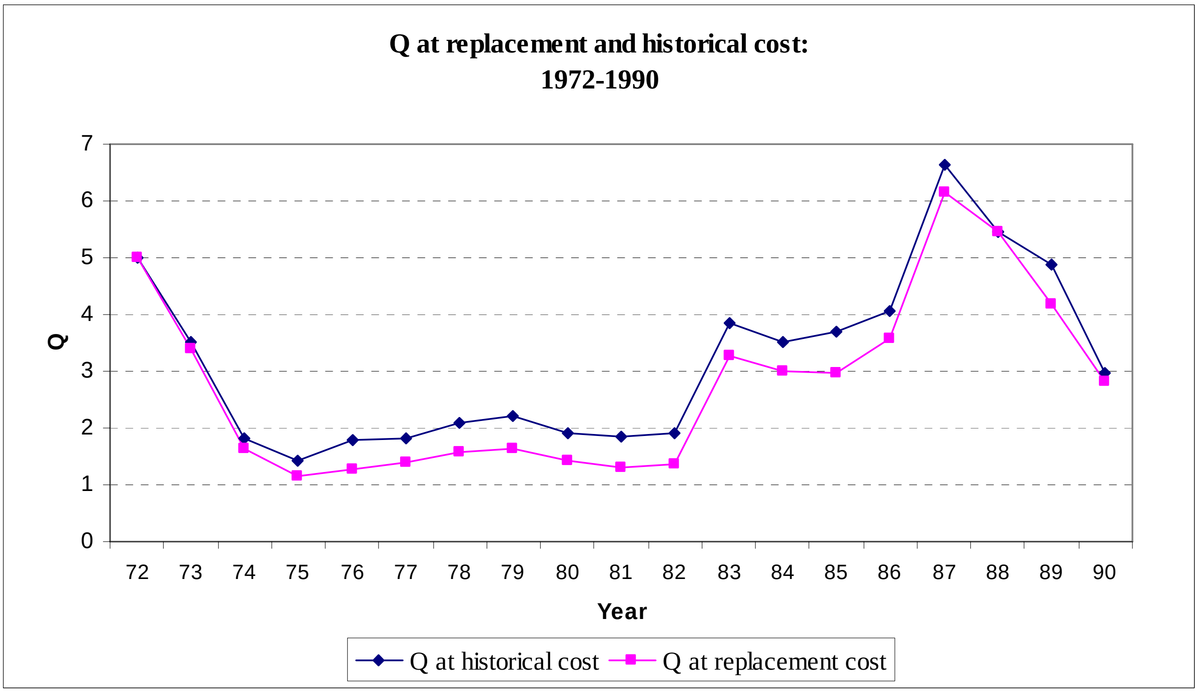
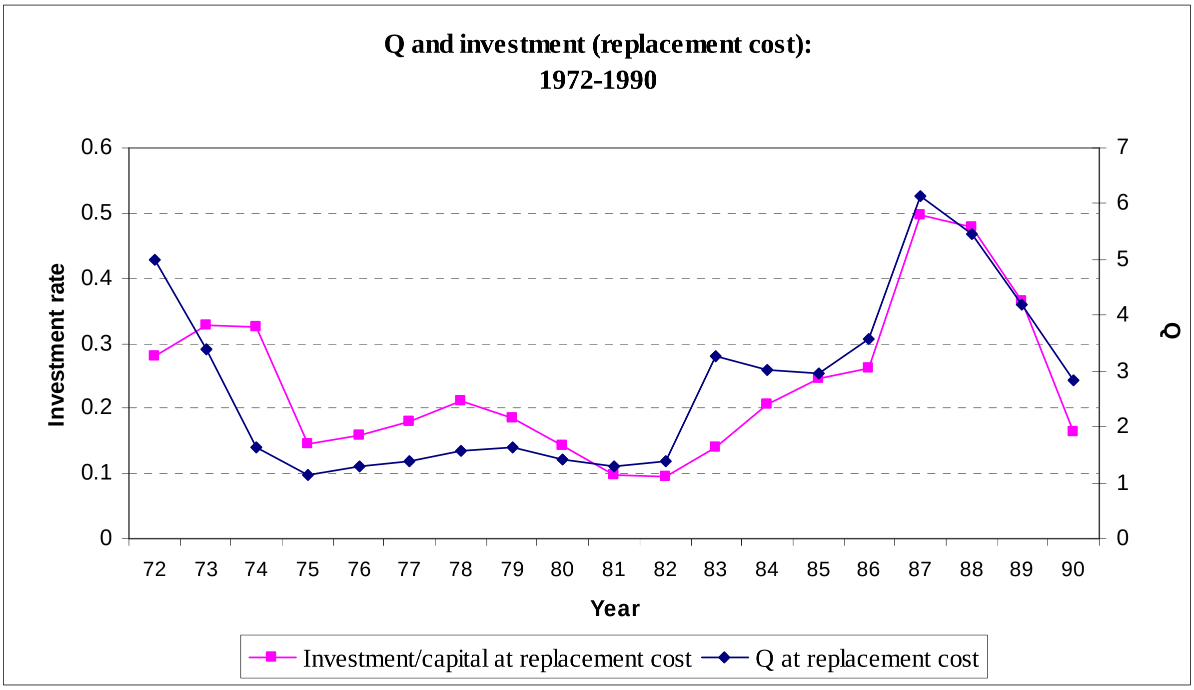


Chart 3



3.1 Estimation of the Q model

Once average *Q* has been constructed the estimation of a *Q* model of investment should be quite straight-forward. However, as already mentioned, a number of issues arise regarding the correct estimation procedure to be applied. Before describing the estimation procedures used here, it should be noted that in what follows the absence of market power for firms is assumed, as in its presence the equality between average *Q* and marginal *q* would break down.

The equation to be estimated is:

$$\left(\frac{I}{K}\right)_{it} = a + \beta Q_{it} + u_{it}\text{, where } u_{it} = \mu_i + \lambda_t + \varepsilon_{it} \qquad (12)$$

$\left(\frac{I}{K}\right)_{it}$ is the investment rate for firm *i* at time *t* (i.e. investment as a ratio of installed capital) and the only explanatory variable is Q_{it}, which represents the market value of the firm as a per cent of installed capital. The structure of the error term is of special interest, as it will determine the appropriateness of alternative estimation procedures. It allows for both an individual effect (which could reflect e.g. management abilities or other firm-specific characteristics) and a time effect, which is essential to capture the missing effect of changing relative prices (investment prices and prices in the goods market), common to all firms over time, as well as cyclical variation in investment. Obviously the individual effects μ_i should be allowed to be correlated with the firm's stock market valuation Q_{it}, i.e. $E(Q_{it}\mu_i) \neq 0$, and hence a fixed-effects estimator should be preferable to a random effects one, as it would deliver unbiased and consistent results. The transitory part of the error term ε_{it} is assumed to be iid with mean zero and a constant variance. An additional assumption is made that *Q* is independent of the time effects. This assumption will be relaxed later on.

Under the assumptions made above it is possible to treat the fixed time-effects as dummies whose coefficients can be estimated. This would be equivalent to an one-way error component model. Since there are only 19 time dummies it is computationally feasible to apply this procedure. Simply estimating the model in the form of deviations from time averages wipes out the individual effects and delivers a consistent[18] estimator. In this case, the Within estimator of β is given by simply running OLS on the transformed model

$$\left(\frac{I}{K}\right)_{it} - \left(\frac{\bar{I}}{K}\right)_{i.} = \beta(Q_{it} - \overline{Q}_{i.}) + \lambda_t + (u_{it} - \bar{u}_{i.}).^{19}$$

The within estimator of β is given in column (1) of Table 2. Only companies for which at least five years of observations on Q are available are used. The coefficient on Q is statistically significant and positive. The joint significance of the individual effects as well as the joint significance of the time dummies is not rejected at a 5% significance level. The constant is positive but not significant. The ρ coefficient which shows the fraction of variance in the dependent variable due to the individual effects is estimated to be 11.4%.

For the sake of comparison, the results of a random effects GLS estimation of the model in column (1) are reported in column (2). As can be seen the point estimate for β decreases marginally compared to the estimate in the first column, while the point estimate for the constant increases but remains statistically insignificant. To choose between random and fixed effects a Hausman (1978) specification test is performed. Under the null of no correlation between the individual effects and the regressor both random and fixed effects provide unbiased and consistent estimators.[20] If the alternative hypothesis is true the fixed effects estimator remains consistent and unbiased while the random effects estimator does not. The Hausman test in which the coefficients on Q as well as on the time dummies are tested rejects the null hypothesis (the test statistic which is distributed as a $\chi^2(19)$ is 45.20 with a probability of exceeding the tabulated value equal to zero). Consequently the fixed effects estimation of column (1) should be preferred. This result confirms the intuition that the estimation of a fixed-effects model rather than a random effects one makes more sense, since in this application a particular sample of firms (which was not drawn randomly, but satisfies certain criteria) is used in order to draw inference on their investment behaviour. It is also perfectly reasonable that the individual effects will be

[18] Asymptotic properties of estimators refer to an increasing N, holding the time dimension constant. Of course the fixed-effects estimator of the individual effects will not be consistent, as the number of μ_i's increases as N tends to infinity.

[19] It is assumed that $\sum_t \lambda_t = 0$, to avoid multicollinearity given the fact that a constant is included in the original model.

[20] Consistency of the fixed effects estimator relies on the assumption made above that there is no correlation between the time effects and the regressor.

correlated with our measure of investment opportunities, *Q*, since for example market valuation of a firm could partly reflect management choices and abilities.

Table 2: Estimation of the *Q*-specification

Regression of I/K on:	Fixed effects (time dummies) (1)	Random effects (time dummies) (2)	Within estimator (Baltagi method) (3)
Q	0.0185291*	0.0181918*	0.0187146*
	(0.0008745)	(0.0007827)	(0.0008744)
Constant	0.086124	0.1146383	
	(0.0922706)	(0.0893364)	
R^2	0.0664	0.0678	0.0497
Within	0.0606	0.0597	
Between	0.1416	0.1661	
Test for joint significance of individual effects	F(778, 8750) =1.18 p>F=0.0006		F(778,8750)=1.117 p>F=0.00
Test for joint significance of time effects	F(19, 8750) =4.58 p > F = 0.0000	X^2(19)=93.57 p>X^2=0.0000	F(19,8750)=4.517 p>F=0.0000
ρ	0.11358802	0.02142471	
Hausman test	$chi^2(1) =3.44*10^6$ Prob>chi^2 = 0.0000	$chi^2(19)$ =45.20 Prob>chi^2 = 0.0010	

Number of observations: 9549
Number of firms: 779
Number of obs. per firm: min.: 5, average: 12.3, maximum: 19

* Significant at a 5% significance level.

The assumption made above of no correlation between the fixed time effects and the regressor is quite stringent, since roughly translated it would mean that „good“ or „bad“ news from the stock exchange cannot be reflected in the cyclical variability of investment. If this assumption is relaxed the fixed effects estimator with the inclusion of time dummies will no longer be consistent. In this case Baltagi (1995) shows that the Within estimator of *β*, derived by running OLS on the transformed model given below, is consistent:

$$\left(\frac{\tilde{I}}{K}\right)_{it} = \beta\tilde{Q}_{it} + \tilde{u}_{it}, \text{ where } \left(\frac{\tilde{I}}{K}\right)_{it} = \left(\frac{I}{K}\right)_{it} - \left(\frac{\bar{I}}{K}\right)_{.t} - \left(\frac{\bar{I}}{K}\right)_{i.} + \left(\frac{\bar{I}}{K}\right)_{..},$$

$$\tilde{Q}_{it} = Q_{it} - \overline{Q}_{i.} - \overline{Q}_{.t} + \overline{Q}_{..} \text{ and } \tilde{u}_{it} = u_{it} - \overline{u}_{i.} - \overline{u}_{.t} + \overline{u}_{..}$$

$\overline{X}_{i.}$ denotes for each individual the average across time of variable X_{it}, $\overline{X}_{.t}$ denotes for each time period the average across individuals of variable X_{it} and $\overline{X}_{..}$ denotes the average of variable X_{it} across time and individuals. By wiping out the individual *and* the time effects this transformation eliminates correlation between the regressor and the error term and hence the derived estimator will be consistent and unbiased.

The results from this estimation are reported in column (3) of Table 2.[21] The coefficient on *Q* is again statistically significant and slightly higher than in the previous two estimations. The R^2 is at around 5%. Using the procedure outlined in Baltagi (1995) the joint significance hypotheses of individual effects and of time effects are tested. The resulting F-statistics are sufficiently large to reject both the hypothesis of individual effects being jointly equal to zero and the hypothesis of time effects being equal to zero at a 1% significance level.

Given the fact that under the null of independence between *Q* and the time effects both the Baltagi Within estimator and the fixed-effects with time dummies give consistent estimates of *β,* but under the alternative hypothesis only the Baltagi estimator is consistent, a Hausman (1978) specification test can be ran to compare the two estimators. The resulting test statistic, distributed as $X^2(1)$ is well above the 5% critical value (3.841), and therefore the null of independence between *Q* and the time effects can be rejected at any statistically meaningful level.

One point which deserves further investigation relates to the possibility of endogeneity of *Q*. One possible reason for endogeneity could be the fact that the individual effects or the time effects are correlated with *Q*. In this case, as has been shown by Mundlak (1978), the fixed effects Within transformation appearing in column (3) delivers a consistent BLUE estimator for *β*. A more interesting case comes up if *Q* is correlated with the transitory part of the error term. In fact the assumptions made about the timing of the investment decision imply that *Q* contains information not only for future but also for current profitability and might therefore be correlated with ε_{it} (the part of the error term which is neither individual-specific nor time-specific). If ε_{it} is thought of as representing a shock to the cost-of-adjustment function, then it will immediately affect the investment rate, but it will also increase *Q*, by increasing the future profitability of investment (it will increase the term

[21] Software-reported standard errors in column (3) are corrected by the term (n-K)/(n-N-T-K+1), to take account of the fact that we use away N+T-1 degrees of freedom to calculate $u_{i.}, u_{.t}$ and $u_{..}$.

$E_t \frac{\partial V_{t+1}(K_t)}{\partial K_t}$ in equation (5')). Therefore an estimation procedure which takes account of possible correlation between *Q* and ε_{it} should be used.

A further point usually made in the empirical literature on *Q* models of investment is that the observed *Q* might be measured with error. In this case an OLS procedure would deliver biased and inconsistent results. The usual fixed effects estimators, e.g. the Within or the First Difference estimator, would be biased downwards. Moreover the regression of investment on *Q* would have a low R^2. Griliches and Hausman (1986) show that estimating difference models of different „lengths" and using appropriate lags or leads of the regressor (or linear combinations thereof) as instruments one could actually get an estimate of the measurement bias.

In an attempt to identify and remedy the two potential problems of measurement error and of endogeneity of *Q* we first estimate the model in first and second differences. According to Griliches and Hausman (1986) the attenuation bias in case of measurement error will be higher in the presence of serial correlation in the true unobserved variable. Since the correlation should be higher the shorter the time length between two observations, there should be less of a downward bias in a difference model of higher order. The results are reported in Table 3. It is quite surprising that the coefficient in the second difference model is lower than the one in the first difference model. A simple t-test of the hypothesis that the two estimates are equal is rejected (t=104.5, p>| t |=0.00). This is an indication of the presence of measurement bias and hence an IV estimation with appropriate lags of the regressor used as instruments should be applied.

An obvious instrument which can be used is the first lag of *Q*. If however *Q* is endogenous, ε_{it-1} will be correlated with Q_{it}-Q_{it-1} in a first difference IV estimation. Therefore only lags of *Q* dated *t-2* or older can be valid instruments. If in addition we assume that the transitory part of the composite error term is not serially correlated then in a model which wipes out individual effects (e.g. Within or First Difference transformation) the transformed error term will not be correlated with the regressor.[22] In column (3) results are reported for an instrumental variables estimation, with lags

[22] It is a bit more complicated in the presence of measurement error, in which case as shown by Griliches and Hausman (1986), the stochastic properties of the measurement error will determine the set of valid instruments. In some extreme cases, where the measurement error is serially correlated but with no obvious structure, the use of external instruments becomes necessary.

of Q dated *t-2… t-5* as well as the time dummies used as instruments. The point estimate of β almost triples, compared to the estimates in Table 2, and remains statistically significant. The R^2 also increases to more satisfactory levels. The statistical significance of the lags of Q in the first stage estimation (regression of Q on the set of instruments) indicates their validity as instruments.

Table 3: Estimation of the *Q*-specification

Regression of I/K on:	First difference estimator (1)	Second difference estimator (2)	IV estimation[1] (Instruments: $Q_{t-2}…Q_{t-5}$ and time dummies) (3)
Q	0.0240191* (0.0011232)	0.0222218* (0.0011216)	0.0531347* (0.0038776)
R^2	0.0534	0.0542	0.1857
Within			0.2296
Between			0.1640
Test for joint significance of time effects	F(18,8734)=1.43 Prob>F= 0.1060	F(18,7950)=2.64 Prob>F=0.0002	
ρ			0.171342
Characteristics of the sample	Number of observations: 8753 Number of firms: 779	Number of observations: 7969 Number of firms: 779	Number of observations: 5616 Number of firms: 717

* Significant at a 5% significance level.
[1]The first difference IV estimation method is used.

More distant lags can also be used as instruments, although the "older" the information the less it should add to the model. The IV estimation results indicate that, if something, the benchmark specifications (fixed effects with time dummies and within estimator) reported in columns (1) and (3) of Table 2, underestimate the effect of Q on the optimal investment rate chosen by the firm. Comparing the results reported in Tables 2 and 3 to the results of various Q model specifications found in the empirical literature, the statistical significance of Q is confirmed, although in the estimations reported here, the economic importance of Q as captured by the magnitude of its coefficient estimate is greater, implying lower and more reasonable adjustment costs.

Table 4: Coefficients on *Q* in the empirical literature*

References	Coefficient on *Q*	Sample	Other regressors
Hayashi and Inoue (1991)	0.027-0.032	687 Japanese firms (1962-86)	--
Hoshi, Kashyap and Scharfstein (1991)	0.006	337 Japanese firms (1977-82)	CF
Chirinko and Schaller (1995)	0.0005	212 Canadian firms (1973-86)	--
Erickson and Whited (2000)	0.014-0.045	737 US firms (1992-95)	--
Fazzari, Hubbard and Petersen (1988)	0.0044-0.0073	422 US firms (1970-84)	--
Blundell et al. (1992)	0.0092-0.0099	532 UK firms (1975-86)	--
Schaller (1990)	0.0038-0.0077 (panel data) 0.0072-0.0096 (synthetic aggregate data)	188 US firms (1951-85)	--

* The purpose of this table is to provide an indicative range of estimates in the literature, not an exhaustive account.

3.2 Estimation of the Euler equation

In contrast to the *Q*-type investment models, the Euler equation specification as given in equations (9) and (11) allows for a distinction to be made between the case of perfect and imperfect competition in the output market. By considering φ_{t+1}, i.e. the real discount factor, constant across two adjacent periods one can estimate for the case of perfect competition an investment model from equation (9), allowing for fixed time dummies to capture the common effect for all firms of changing cost of capital and possible cyclical variation in the investment rate over time.

The investment rate is defined as before, i.e. investment in fixed assets as a percentage of existing capital stock at replacement cost at the end of the previous period. The equation to be estimated includes as regressors the lag of the investment rate, the square of the lagged investment rate and the lag of cash-flow. Cash-flow is constructed from the EXSTAT profit and loss accounts data, as profits minus tax minus interest expenses divided again by the replacement cost of capital stock at the end of period *t-1*.

Since equation (9) includes the lagged dependent variable as a regressor an OLS estimation would give biased and inconsistent estimators and therefore an alternative estimation methodology should be applied. Arellano and Bond (1991) assume a dynamic panel data model of the type:

$$y_{it} = \delta y_{it-1} + \sum_j \beta_j X_{j,it} + \sum_k \gamma_k W_{k,it} + \mu_i + \varepsilon_{it} \qquad (13)$$

where the X_j 's are exogenous covariates and the W_k 's are predetermined variables. By first differencing they wipe out the individual effects and transform the above model to one which can be estimated by GMM, exploiting the orthogonality conditions between lagged values of the dependent variable and the transformed error term. In particular, the model in first differences becomes:

$$y_{it} - y_{it-1} = \delta(y_{it-1} - y_{it-2}) + \sum_j \beta_j (X_{j,it} - X_{j,it-1}) + \sum_k \gamma_k (W_{k,it} - W_{k,it-1}) + (\varepsilon_{it} - \varepsilon_{it-1}) \qquad (14)$$

Now y_{it-2} can be used as an instrument in a GMM estimation of (14) since it is correlated with $(y_{it-1} - y_{it-2})$, but it is orthogonal to the transformed error term $(\varepsilon_{it} - \varepsilon_{it-1})$, as long as ε_{it} is serially uncorrelated. If ε_{it} is MA(q) then all lags of the dependent variable dated *(t-q-2)* and older can be used as instruments. In addition to that, the Arellano and Bond estimation procedure uses a maximum of (*t-p-1)* lags[23] of the predetermined variables and differences of the exogenous variables as instruments. Hence a sufficiently large set of instruments is included and the estimates of the parameters in (14) should be consistent.

In our estimation, the time dummies are treated as exogenous covariates, the square of lagged investment is treated as endogenous and the lag of cash-flow is treated as predetermined. Results for the one-step Arellano-Bond estimation are reported in column (1) of Table 5. The one-step estimation is more suitable for inference, especially in the presence of weak instruments. This is particularly so, since estimated standard errors of the two-step estimators have been found to be downward biased in Monte Carlo studies. Heteroskedasticity robust standard errors are reported in parentheses.

From the coefficient estimates reported in column (1) of Table 5 only lagged investment and its square are statistically significant. Although both bear the correct signs, they are numerically far from the values consistent with the theory (around 1 for lagged investment and 0.5 for its square). The coefficient of lagged cash-flow, is as expected negative, but statistically insignificant. The Arellano-Bond test for autocorrelation in the residuals of order (1) and (2) is rejected at the 5% significance level. Finally, the Sargan's test statistic for overidentifying restrictions is rejected, suggesting invalidity of some of the instruments used. Further attempts to modify the

[23] Where p is the number of lags of the predetermined variable appearing in the model.

instrument set by specifying a maximum number of lags of the dependent and other variables to be used as instruments did not improve the results.

Column (2) reports results on the Euler equation for investment for the case of imperfect competition in the output market. With the exception of lagged investment which has now a negative effect, all coefficients bear the correct signs, but are

Table 5: Estimation of the Euler equation for investment

Regression of I/K on:	Arellano-Bond one-step GMM[a]: perfect competition (1)	Arellano-Bond one-step GMM[a]: imperfect competition (2)
$\left(\frac{I}{K}\right)_{t-1}$	0.0817639** (0.0485802)	-0.1457376 (0.1965529)
$\left(\frac{I}{K}\right)^2_{t-1}$	-0.0014167* (0.0004688)	-0.0002128 (0.0020181)
$\left(\frac{C}{K}\right)_{t-1}$	-0.0231248 (0.0399883)	-0.3706871 (0.3176917)
$\left(\frac{Y}{K}\right)_{t-1}$		0.0454015 (0.0418501)
Test for autocorrelation in residuals of order 1	z = -1.94 Pr > z = 0.0520	z = -3.01 Pr > z = 0.0026
Test for autocorrelation in residuals of order 2	z = 0.26 Pr > z = 0.7986	z = -0.48 Pr > z = 0.6277
Sargan's test of overidentifying restrictions	$chi^2(545)$ = 888.55 Prob >chi^2 =0.0000	$chi^2(733)$ = 4277.82 Prob > chi^2=0.0000
Characteristics of the sample	Nr of obs: 8756 Nr of firms: 779 Avg obs per firm: 11.2	Nr of obs: 8753 Nr of firms: 779 Avg obs per firm: 11.2

[a] Robust standard errors are reported.

statistically insignificant. Autocorrelation of order (1) is detected in the residuals, while the Sargan test statistic rejects the validity of the instruments used. All this suggests a very poor fit of the Euler equation to the available data set, especially in the case of imperfect competition.

3.3 Robustness analysis

Although the results in the previous sections on the *Q* model as well as on the Euler equation would allow for a first qualitative conclusion on the relative performance of the two alternative empirical models, a more conclusive statement can only be formulated after a robustness analysis has been performed. Three different robustness tests are performed in the following sub-sections. In the first, the sample is restricted to firms with more than 10 observations, while the next two are based on alternative sample splits suggested in the literature to test for the validity of the neoclassical assumptions. This is usually done by adding variables like cash-flows or output in a *Q* model (see e.g. Fazzari, Hubbard and Petersen; 1988) or a debt term and a dividend term in Euler equations (see e.g. Bond and Meghir; 1994) and estimating for different sample splits. However, since the object of this paper is to test empirically the two different theoretical models, no extra variables are added. If financial constraints play a role for investment this should lead to lower explanatory power and lower coefficients for the group of firms which is identified as financially constrained.

A caveat of this methodology is that firms are *a priori* classified as being likely to face financial constraints which invalidate the neoclassical assumptions on the basis of some of their characteristics which could reveal problems in the communication of information. This does not allow the study of the longitudinal dimension of financial constraints, e.g. it does not take account of the fact that a firm which is financially constrained today, might not be tomorrow and *vice versa*. Despite this shortcoming, this methodology has proved useful for the study of financial constraints and it is applied in the following sub-sections.

3.3.1 Firms with more than 10 observations

The original results have been reported for firms with at least 5 observations in the sample. This number of sample periods is large enough to bring out the time dimension of the panel data, but it is also quite unrestrictive since firms with relatively few in-sample observations are included. By now constraining our estimation to firms with more than 10 records we pick up firms with a longer track record, for which the neoclassical assumptions are more likely to hold: the longer the track record of a company the less information problems it would face and the less financially constrained it should therefore be. For example because the evaluation of young firms by financial institutions is more costly.[24]

Of course it is not necessarily true that the track record based on the observations of this sample reflects the track record of a certain company in the market. In fact, the lack of more observations for these particular firms might indicate either that they were "born" after 1970, or that they "died" before 1990, or even that they were not listed for some part of the 1970-1990 period. In the former case, these are young and non-established firms which according to the existing literature are more likely to face information-related financial constraints, so that the neoclassical assumptions are less likely to hold for them. Also in the last case, the fact that the firms were for some reason not listed for a large part of the sample period makes them more vulnerable to financial constraints, since being listed on the stock exchange mitigates partly information asymmetries because it increases transparency of a firm's financial accounts. Finally, a firm which has less than 5 in-sample observations because it "died" before 1990, must have either been "born" after the sample start (so it falls to the category of "young") or must have not been listed for some part of the sample before it actually "died" (in which case the argument of higher information asymmetries facing non-listed firms applies). Hence, although the number of in-sample observations cannot be used as a proxy for firm's age, it can however be used as a criterion for information-related asymmetries and, consequently, it can be used for testing the validity of the neoclassical assumptions.

The firms included in this second estimation are now much less (527 compared to 779 before), while the mean sample size becomes slightly larger (£115 million compared to £112 million before). Table 6 reports the results for Q specification estimations for firms with more than 10 observations. The results are qualitatively virtually unchanged, but coefficients on Q are now higher for all types of estimation (t-test for the difference of the coefficients estimated with the fixed effects with time dummies on the whole and the restricted sample is 2,200, Prob > | t | = 0.0000) and the explanatory power of the various specifications as captured by R-squared has also markedly increased. Furthermore, it should be noted that the Hausman test clearly rejects both the hypothesis that estimates from the fixed and the random effects model

[24] As Deputy Governor McMahon of the Bank of England put it: *"…the long-term institutions find it unrewarding to spend time assessing new or small firms as credit risks, preferring instead to channel large blocks of funds into well-recognised companies"* [QB, vol. 21, issue 1, p. 73].

are not systematically different and the hypothesis that estimates from the two fixed effects models (one based on the Baltagi method and the other on the inclusion of time dummies) are not systematically different. This allows us to conclude that our choice of a fixed effects estimation is appropriate and that among the two fixed effects estimations the Baltagi method should be preferred. The results generally show that the *Q* model is robust to the length of the track record for our sample of firms. Moreover, it suggests that the longer the track record the higher the probability that the assumptions of the neoclassical model apply for the firms under consideration.

Table 6: Estimation of the *Q*-specification

Regression of I/K on:	Fixed effects (Baltagi method) (1)	Fixed effects (time dummies) (2)	Random effects (time dummies) (3)	IV estimation (Instruments: second lag of *Q* and time dummies) (4)
Q	0.06724 *	0.0674193*	0.0602889*	0.0443319*
	(0.0020283)	(0.0020472)	(0.0017972)	(0.0032961)
Constant		-0.0067289	0.0108983	--
		(0.0998913)	(0.0978316)	
R^2	0.1308	0.1357	0.1359	0.2039
Within		0.1407	0.1405	0.2307
Between		0.1463	0.1489	0.2142
Test for joint significance of individual effects	F(526, 7305)= 1.13 Prob > F = 0.0246	F(526, 7305)= 1.18 Prob > F = 0.0045	--	
Test for joint significance of time effects	F(19,7305) =1.357 Prob > F = 0.1367	F(19, 7305) = 2.00 Prob > F = 0.0061	chi2(19) = 36.71 Prob > chi2 =0.0086	
ρ		0.08128004	0.00378242	0.15862991
Hausman test	$chi^2(1)$=89.91 Prob > chi^2 = 0.0000			
Hausman test		chi2(20) = 86.59 Prob>chi^2 = 0.0000		
Characteristics of the sample	Nr. of obs.: 7852 Nr. of firms: 527 Avg. obs. per firm: 14.9			Nr. of obs.: 5182 Nr. of firms: 527 Avg. obs. per firm: 9.8

* Significant at a 5% significance level.

In Table 7 results for the Euler equation for the restricted sample are reported. The results do not show a marked improvement like in the case of the *Q* model. Now in the case of perfect competition the coefficient of lagged investment becomes statistically insignificant but the coefficient on lagged cash-flow is statistically significant and bears the correct (negative) sign. There is an improvement for the estimation in the case of imperfect competition. Although lagged investment has a negative and statistically insignificant coefficient, the rest of the coefficients have the correct signs and lagged cash-flow and output are statistically significant. It appears that the imperfect competition version provides a better description for investment behaviour in the case of firms with a longer track record. The Sargan test statistic still rejects the validity of the instruments used for both versions of the market structure. In general however, the results imply that even restricting the sample to firms with more in-sample information does not change the fact that the investment model based on the Euler equation appears to be problematic.

Table 7: Estimation of the Euler equation for investment

Regression of I/K on:	Arellano-Bond one-step GMM [a]: perfect competition (1)	Arellano-Bond one-step GMM [a]: imperfect competition (2)
$\left(\frac{I}{K}\right)_{t-1}$	0.1010387 (0.0713791)	-0.1591792 (0.1739175)
$\left(\frac{I}{K}\right)^2_{t-1}$	-0.0018939** (0.0011456)	-0.0013842 (0.0019032)
$\left(\frac{C}{K}\right)_{t-1}$	-0.0960395* (0.0465967)	-1.360656** (0.7117792)
$\left(\frac{Y}{K}\right)_{t-1}$		0.0900324** (0.0491973)
Test for autocorrelation in residuals of order 1	z = -1.60 Pr > z = 0.1086	z = -3.74 Pr > z = 0.0002
Test for autocorrelation in residuals of order 2	z = -0.24 Pr > z = 0.8133	z = -1.48 Pr > z = 0.1384
Sargan's test statistic for overidentifying restrictions	chi2(545) = 1613.76 Prob > chi2=0.0000	chi2(733)= 4346.73 Prob >chi2 =0.0000
Characteristics of the sample	Nr of obs: 7592 Nr of firms: 527 Avg obs per firm: 13.8	Nr of obs: 7289 Nr of firms: 527 Avg obs per firm: 13.8

[a] Robust standard errors are reported.

3.3.2 Large vs. small firms

In the investment literature the point is frequently made that large firms face potentially less information problems (because size is often associated with the age and the market power of a firm or just because a large firm can draw on a relatively bigger collateral pool) and hence the assumptions of the neoclassical model would be more likely to hold for them than for small (and maybe young, less established, etc.) firms. In particular this means for the *Q* model that a given increase in *Q* will increase the desired capital stock and therefore the optimal investment rate for all firms, however large firms, which face less financial constraints will be able to actually invest more, while small firms lacking internal sources of finance might not be able to match the increase in desired capital stock with an increase in realised investment.[25] Similarly in the dynamic model of investment, an increase in desired capital stock in period *t*, will translate in higher observed investment rates for large than for small firms (sensitivity of investment to its determinants should be higher for the former than for the latter). If this is indeed the case both our specifications should fit better for large than for small firms. This finding would also suggest that a bad fit of our two alternative specifications might be attributable to information problems and, consequently, to financial constraints.

As described in Section 2, we divide firms into three categories, characterized as small, medium and large. The limits between the three categories are the 33rd and the 66th percentile of the average (across time) size distribution of firms in our sample. We report only results for small and large firms, i.e. for the two tails of the size distribution, to make differences based on the size of the firms more clear.[26]

The results for three types of *Q* specifications (the Within estimator for the two-way error component model, the fixed effects estimator with time dummies and the IV first difference estimation with $Q_{t-2}...Q_{t-5}$ and the time dummies used as instruments) are reported in Table 8 for small and large firms. It is obvious from the results that the explanatory power of the *Q* model is much higher for large firms than for small. Furthermore, in all estimations the coefficients on *Q* are much higher for large firms than for small, even compared to the whole sample estimation reported in Table 2.

[25] In the March 1981 Budget measures were announced to encourage the provision of finance also to small firms. *"...there are signs that some financial institutions are expanding their business in this area. The clearing banks now operate or participate in schemes to provide medium-term and long-term finance and even equity capital, to small firms"* [Lecture by the Bank of England Deputy Governor McMahon, QB, vol. 21, issue 1, p. 73].

[26] An alternative approach, in which a dummy for size is interacted with *Q*, gives almost identical results.

Table 8: Estimation of the Q-specification – large vs. small firms

	Within estimator (Baltagi method)		Fixed effects (time dummies)		IV estimation (Instruments: Q_{t-2} … Q_{t-5} and time dummies)	
Regression of I/K on:	SMALL (1)	LARGE (2)	SMALL (3)	LARGE (4)	SMALL (5)	LARGE (6)
Q	0.0144362* (0.0007817)	0.1752118* (0.0055625)	0.0142603 * (0.0007784)	0.2325873* (0.0063956)	0.0470946* (0.0044512)	0.2590672* (0.0192601)
Constant			0.2068646 (0.1349221)	-0.2880366* (0.0965486)		
R^2	0.1078	0.2483	0.1446	0.3268	0.2662	0.2835
Within			0.1391	0.3175	0.3097	0.2184
Between			0.2527	0.5259	0.1471	0.5376
Test for joint significance of individual effects	F(288, 2825)=0.85 Prob > F = 0.9635	F(225, 3003) =2.92 Prob > F = 0.0000	F(288, 2825) = 0.98 Prob > F = 0.5893	F(225, 3003) = 2.98 Prob > F = 0.0000		
Test for joint significance of time effects	F(18,2825)=3.452 Prob > F = 0.0000	F(19, 3003) = 9.56 Prob > F = 0.0000	F(18, 2825) = 5.07 Prob > F = 0.0000	F(19, 3003) = 5.43 Prob > F = 0.0000		
ρ			0.10368864	0.24567706	0.14741088	0.26319192
Characteristics of the sample	Number of obs: 3133 Number of groups: 289 Avg. obs. per group: 10.8	Number of obs: 3256 Number of groups: 231 Avg. obs. per group: 14.1	Number of obs: 3133 Number of groups: 289 Avg. obs. per group: 10.8	Number of obs: 3249 Number of groups: 226 Avg. obs. per group: 14.4	Number of obs: 1683 Number of groups: 259 Avg. obs. per group: 6.5	Number of obs: 2110 Number of groups: 216 Avg. obs. per group: 9.8

* Significant at a 5% significance level.

In Table 9 results for the Euler equation of investment are reported for both perfect and imperfect competition and for the small and large size groups. The results allow us to draw some general conclusions. First, irrespective of the assumptions made regarding the structure of the product market, the Euler equation for investment appears to be a very poor description of the investment behaviour of *small* firms. In the case of both perfect and imperfect competition, only lagged cash-flow has a statistically significant coefficient. The Sargan test statistic in both cases suggests invalidity of the instruments used, while autocorrelation of the residuals of order 1 is not rejected.

Table 9: Estimation of the Euler equation for investment-large vs. small firms

	Perfect competition		Imperfect competition	
Regression of I/K on:	Arellano-Bond one-step GMM [a]: SMALL (1)	Arellano-Bond one-step GMM [a]: LARGE (2)	Arellano-Bond one-step GMM [a]: SMALL (3)	Arellano-Bond one-step GMM [a]: LARGE (4)
$\left(\frac{I}{K}\right)_{t-1}$	-0.026985 (0.0801879)	-0.027743 (0.128666)	0.0085363 (0.0788857)	-0.3704659* (0.1559759)
$\left(\frac{I}{K}\right)^2_{t-1}$	-0.0013768 (0.0083998)	-0.0013239 (0.0017555)	-0.0053222 (0.0077617)	-0.0007129 (0.0027257)
$\left(\frac{C}{K}\right)_{t-1}$	-0.0632769* (0.0316267)	2.710452* (1.205716)	-0.0541499* (0.0246845)	0.8611791 (0.657798)
$\left(\frac{Y}{K}\right)_{t-1}$			-0.0029712 (0.0024233)	0.1400847* (0.0306514)
Test for autocorrelation in residuals of order 1	z = -4.10 Pr > z = 0.0000	z = -1.29 Pr > z = 0.1958	z = -4.17 Pr > z = 0.0000	z = -1.90 Pr > z = 0.0570
Test for autocorrelation in residuals of order 2	z = -1.12 Pr > z = 0.2625	z = -1.44 Pr > z = 0.1501	z = -1.47 Pr > z = 0.1425	z = -1.41 Pr > z = 0.1573
Sargan's test statistic for overidentifying restrictions	chi2(492) = 598.77 Prob >chi2 =0.0007	chi2(492)= 1590.15 Prob >chi2 =0.0000	chi2(662) = 1090.20 Prob > chi2=0.0000	chi2(662) = 2730.02 Prob > chi2=0.0000
Characteristics of the sample	Nr of obs: 2846 Nr of firms: 290 Avg obs per firm: 9.8	Nr of obs: 3001 Nr of firms: 231 Avg obs per firm: 13	Nr of obs: 2843 Nr of firms: 290 Avg obs per firm: 9.8	Nr of obs: 3001 Nr of firms: 231 Avg obs per firm: 13

* Significant at a 5% significance level.
** Significant at a 10% significance level.
[a] Robust standard errors are reported.

The picture becomes more puzzling however, when considering the results for large firms. In the perfect competition version all coefficients apart from the one on the cash-flow term are insignificant. It is rather difficult to interpret the finding that the coefficient on lagged cash-flow appears to be positive and not only statistically significant but also of great economic importance for the determination of the investment behaviour of large firms. In the Euler equation set-up cash-flow represents marginal revenue expected from new capital, so that the higher the cash-flow in period *t-1* the less the firm should invest in period *t* (a reallocation of investment expenditure should occur towards period *t-1*, where it is more profitable). This finding could be explained by the presence of financial constraints, but again using size as a proxy for possible information asymmetries, cash-flow should be important for small firms, but not (or at least less) important for large firms.

In the case of imperfect competition the coefficient of lagged investment is statistically significant but negative. The cash-flow coefficient still bears the wrong sign, but becomes now statistically insignificant. Finally the output term bears the correct sign and appears to be statistically and economically significant. Hence for large firms imperfect competition appears to be the most likely case but coefficients on the other variables included in the Euler equation are either statistically insignificant or bear the wrong sign or both.

3.3.3 Firm dividend policy

Finally it has been argued in the literature that the dividend policy of a firm can be used to identify possible financial constraints that it faces. If there are no financial constraints the firm faces a horizontal supply of finance, i.e. it can raise an infinite amount of funds at a given price to finance profitable investment projects. However, information asymmetries can cause financial constraints to bind for the firm. In this case the firm will use up its internal finance (which is priced at a constant rate) and then it will have to resort to external finance whose price is increasing in the amount of funds raised. This behaviour implies a financial „pecking order“. A part of the empirical literature on investment identifies financial constraints from the dividend policy of the firm. For example, a firm which cuts its dividends or which pays zero dividends for more than one consecutive period is likely to face some financial constraints which force it to use all available internal finance before resorting to the more costly external finance for the realisation of its investment projects. In this case, if the cost of external finance is too high some projects which would be considered profitable in the absence of financial constraints will not be materialised.

For the division of the sample into financially constrained and unconstrained firms (actually firms which are more or less likely to be financially constrained), the average across time dividend (as per cent of available profits) of each firm is computed and the firms are divided into three groups: low, medium and high dividend paying firms. The boundaries between the three groups are the 33rd and the 66th percentile of the dividend distribution. The rationale behind this sample division is simple. Firms paying high dividends have a sufficient cushion for absorbing shocks in the availability of internal finance in the presence of profitable investment projects. A firm which pays high dividends can cut down on its dividend payments to finance its investment and therefore it is less likely to be financially constrained. In the contrary, low dividend paying firms do not have this cushion and in the absence of internal finance they might be forced to forego profitable investment opportunities. In Table 9 the regression results of the *Q* model for the lowest and highest dividend paying group of firms are reported.

Table 10: Estimation of the *Q*-specification – dividend policy

	Fixed effects (time dummies)		IV estimation (Instruments: $Q_{t-2} \ldots Q_{t-5}$ and time dummies)	
Regression of I/K on:	CONSTRAINED (1)	NOT CONSTRAINED (2)	CONSTRAINED (3)	NOT CONSTRAINED (4)
Q	0.0129876* (0.0009557)	0.0232714* (0.0021423)	0.1932306* (0.0203674)	0.0706073 * (0.0047604)
R^2	0.0614	0.0378	0.0911	0.2198
Within			0.1505	0.2519
Between			0.0371	0.2066
Test for joint significance of individual effects	F(279,2823)=1.54 Prob > F = 0.0000	F(256,3006) =0.86 Prob > F = 0.9427		
Test for joint significance of time effects	F(18,2827)= 3.05 Prob > F = 0.0000	F(19,3006) = 1.04 Prob > F = 0.4097		
ρ			0.44426317	0.21423017
Characteristics of the sample	Nr. of obs.: 2846 Nr. of firms: 280 Avg. obs. per firm: 10.2	Nr. of obs.: 3283 Nr. of firms: 257 Avg. obs. per firm: 12.8	Nr. of obs.: 1711 Nr. of firms: 252 Avg. obs. per firm: 6.8	Nr. of obs.: 1984 Nr. of firms: 240 Avg. obs. per firm: 8.3

* Significant at a 5% significance level.

The results in Table 10 are surprising given what would be expected according to the theory. The fixed effects with time dummies method gives a higher coefficient estimate for *Q,* but a lower R^2 for unconstrained firms. On the other hand the IV estimation with Q_{t-2} ... Q_{t-5} and the time dummies used as instruments results in a much higher coefficient for constrained firms, but a lower coefficient of determination.

One possible explanation for this puzzling result is that the dividend policy of a firm might not only reflect the availability of financial resources. It is possible that taking into account free cash-flow considerations shareholders “enforce” a high dividend policy to limit cash-flow available to managers, i.e. as a way of internal monitoring. In this case for high-dividend paying firms average *Q* as measured by the market is higher than average *Q* as observed by firm management, the latter being important for the determination of firm investment. Measurement error will differ between the constrained and the unconstrained group.

Another possible explanation is that the dividend payout ratio is determined endogenously, i.e. firms facing a positive shock in the cost-of-adjustment function will reduce dividend payments to finance profitable investment, while firms which face negative adjustment shocks will be able to increase dividend payments, since investment will not be equally profitable for them. In this case firms with good investment opportunities would fall into the category of constrained, while firms with actually worse investment opportunities will be identified as unconstrained based on their dividend payments. This could explain the higher coefficient in the case of unconstrained firms (Blinder, 1988). However, this explanation is less plausible given the fact that the dividend-based classification of firms is applied by averaging dividend-payments over a longer period of time.

Similarly, Table 11 reports results for the two parts of the sample based on the Euler equation for investment. Once more it becomes obvious that an attempt to identify financially constrained firms and allow them to have a different investment behaviour, changes the results of the Euler equation for investment in a rather unexpected way, compared to the baseline estimations. For constrained firms, in the case of perfect competition, coefficients on lagged investment and its square are statistically significant and bear the correct sign, while lagged cash-flow is statistically insignificant and has a positive sign. In the case of imperfect competition only the square of lagged investment is statistically significant, while the coefficient on output is insignificant.

Table 11: Estimation of the Euler equation for investment-dividend policy

	Perfect competition		Imperfect competition	
Regression of I/K on:	Arellano-Bond one-step GMM [a]: CONSTRAINED (1)	Arellano-Bond one-step GMM [a]: UNCONSTRAINED (2)	Arellano-Bond one-step GMM [a]: CONSTRAINED (3)	Arellano-Bond one-step GMM [a]: UNCONSTRAINED (4)
$\left(\frac{I}{K}\right)_{t-1}$	0.1722848* (0.0867944)	0.1184274 (0.1342299)	0.1306665 (0.0889148)	-0.3969485 (0.2590274)
$\left(\frac{I}{K}\right)^2_{t-1}$	-0.0110318* (0.002896)	-0.0024144 (0.0021278)	-0.0115245* (0.0027865)	0.0005684 (0.0038045)
$\left(\frac{C}{K}\right)_{t-1}$	0.0407246 (0.0721288)	0.0219558 (0.0365917)	0.0347087 (0.066766)	-0.8683097* (0.2293979)
$\left(\frac{Y}{K}\right)_{t-1}$			0.0037553 (0.0043346)	0.1348621 (0.0354843)
Test for autocorrelation in residuals of order 1	z = -2.41 Pr > z = 0.0158	z = -1.33 Pr > z = 0.1844	z = -2.33 Pr > z = 0.0199	z = -3.10 Pr > z = 0.0019
Test for autocorrelation in residuals of order 2	z = -2.02 Pr > z = 0.0436	z = 0.25 Pr > z = 0.8029	z = -2.30 Pr > z = 0.0216	z = 1.48 Pr > z = 0.1380
Sargan's test statistic for	chi2(545) = 669.11 Prob > chi2 =0.0002	chi2(492) = 1343.12 Prob > chi2 = 0.0000	chi2(733) = 993.87 Prob >chi2 =0.0000	chi2(662) = 2367.60 Prob > chi2 = 0.0000
	No of obs.: 2856 No of firms: 280 Avg. obs. per firm: 10.2	No of obs.: 3022 No of firms: 257 Avg. obs. per firm: 11.8	No of obs.: 2843 No of firms: 280 Avg. obs. per firm: 10.2	No of obs.: 3022 No of firms: 257 Avg. obs. per firm: 11.8

* Significant at a 5% significance level.
** Significant at a 10% significance level.
[a] Robust standard errors are reported.

For unconstrained firms, in the case of perfect competition no coefficient appears to be significant. Only in the case of imperfect competition the coefficient on lagged cash-flow is statistically and economically significant and bears the correct sign. However, the insignificance of the lagged output term, suggests that imperfect competition should not be the preferred version for unconstrained firms.

4. Conclusions

This paper made a comparison of the empirical fit of Euler equations for investment and of *Q*-type models of investment, based on a sample of British quoted manufacturing firms. Keeping in mind general criticism of the two approaches, e.g. the fact that *Q* models can only be estimated for stock market listed firms or that marginal *q* is an unobservable variable and has to be aproximated by a constructed variable which may entail significant measurement error, the empirical results imply a relative superiority of the *Q* model. This of course only in the sense that estimations deliver results consistent with theory, and the model specifications are not rejected. The fact remains that in the whole sample estimations *Q* appears to have a quite low explanatory power for investment and the estimated coefficients on *Q* are small, suggesting the presence of unreasonably high adjustment costs.

Some additional interesting conclusions can be drawn from the robustness analysis. Although this type of a priori classification of firms to test for the validity of the neoclassical assumptions has been often criticized, however, in the case of the *Q* model it has been possible to show that this specification provides a better description of reality for firms which have a long track record and large firms, while it has been a very (or relatively) poor description of investment behaviour for firms with short track records and small firms. This could be attributed to financial constraints which are more likely to bind for firms displaying the latter characteristics. An attempt to classify firms on the basis of their dividend policies failed to deliver the expected results, indicating that dividend policy does not provide the necessary information content to reveal possible financial constraints.

Regarding the Euler investment model, the results have been quite disappointing. In the baseline model, all variables had the correct signs as predicted by the theory, however only lagged investment and its square appeared to be statistically significant. The perfect competition version appeared to be more appropriate for the whole sample estimation. However, the robustness analysis proved that the coefficient estimates are extremely instable across different sample splits and so is the inference on the statistical significance of various determinants of investment.

Given the fact that both models have a common framework as a starting point, the overall conclusion is that there is not enough evidence against the general neoclassical framework, however both models (one more than the other) fail to give an adequate explanation for variability in investment.

APPENDIX

Data definitions

Cash flow: Profit minus taxes minus interest expenses.

Investment rate: Investment is the sum of investment in property and other tangible assets. It is calculated as the difference in the stock of property and other tangible assets in two consecutive years. The investment rate is then calculated as the ratio of investment to the replacement cost of fixed assets at the end of the previous period.

Loans: Ratio of bank loans (variable c148 in EXSTAT database) to total assets.

Net assets: The difference between total assets and total current liabilities. Companies with negative net assets are excluded from the sample.

Retained earnings: Profits available for dividends minus cost of preference dividends minus cost of equity dividends, as a percentage of profits available for dividends.

Size: Net assets deflated by the gross fixed capital formation deflator (GDFCF) series.

Sales: Total sales or turnover (variable c31 in the EXSTAT database) as a percentage of the replacement cost of fixed assets in the previous period.

Sales growth: The difference between the logarithm of the variable c31 (see explanation: *sales*) in two consecutive years.

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