The Q Theory of Investment: does uncertainty matter?

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Abstract

This paper includes uncertainty in the Q-model of investment. A structural Q-type investment model is derived, which contains the information on uncertainty effects of random variables that affect the future profitability of a firm. We use a panel of 82 Dutch firms to test whether the presence of uncertainty affects the performance of the Q-model. Our evidence shows that the volatility of profits and the volatility of the interest rate influence investment apart from Q. Moreover, the presence of uncertainty factors changes the structural parameters of the Q-model of investment. The results suggest that the unsatisfactory empirical performance of the standard Q-model of investment may be due to the omission of uncertainty considerations. In addition, Dutch firm-level evidence shows that severe uncertainty effects are associated with small firms and highly indebted firms, which are more likely to be in financial distress. This provides indirect evidence that the wedge between external financing and internal financing aggravates the effect of uncertainty on investment.

Key words: The Q Theory of Investment, Uncertainty, Capital Market Imperfections

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The Q-theory of investment states that all fluctuations in investment are related to marginal Q, i.e. the ratio of the shadow value to the market price of a unit of capital. One of the advantages of the Q-theory of investment is that it explicitly considers expected future profitability, and hence should account for the effect of uncertainty embedded in the future variables that are relevant to investment decisions. The standard Q-theory of investment implies that all factors, including different aspects of uncertainty, affect corporate investment through Q (Blanchard and Fischer 1989). However, the empirical performance of the standard Q-model of investment is disappointing (Chirinko 1993, Blundell, Bond, and Meghir 1992). The explanatory power of the Q-model is often very low; the unexplained part of investment is usually highly serially correlated. This suggests that the model suffers from omitted variable bias.

Many authors try to examine why the empirical Q-model of investment behaves unsatisfactorily. One of main reasons seems to be that marginal Q is unobservable. Often average Q is used to proxy for marginal Q.\(^2\) Since average Q is a perfect proxy for marginal Q only if markets are perfectly competitive and there is a homogeneous production technology (Hayashi 1982), this obviously introduces severe measurement errors.\(^3\) Related to measurement problems, it appears that Q does not carry all the information relevant to investment decisions. Other variables such as cash flow and the changes in output are often found to be significant in explaining investment. The implicit assumption in the standard Q-theory of investment that a firm’s capital structure is irrelevant to investment decisions is found to be another reason why the empirical Q-model of investment

\(^2\) For an attempt to measure marginal Q directly, see Abel and Blanchard (1986).
behaves unsatisfactorily. Poterba and Summers (1983), Hayashi (1985), and Chirinko (1987), among others, investigate the relationship between marginal Q and average Q when both investment decisions and financial decisions are taken into account simultaneously. Both Hayashi and Poterba and Summers find that the Q-theory of investment does not hold for the financing regime where incremental investment is entirely debt-financed. On the other hand, on the basis of empirical evidence, Chirinko concludes that the source of the misspecification in the standard Q-model of investment is not related to the treatment of financial policies. More recently, Scaramozzino (1997) explains the unsatisfactory performance of the Q-model of investment by pointing at the irreversibility of investment and the existence of capital market constraints. Another direction of re-examining the Q-model of investment is to modify the adjustment cost function that is used in deriving the standard Q-model of investment. This theme of research is within the framework of irreversible investment under uncertainty. Abel and Eberly (1994) introduce the fixed cost of capital and irreversibility (the difference between the purchase price and the resale price of capital) into the traditional adjustment cost function. They show that the relationship between investment and Q is no longer linear. Empirical proofs of the nonlinearity between investment and Q are given in Eberly (1997) and Barnett and Sakellaris (1998). The empirical Q-model of investment may be improved by taking into account that not all variables affect investment through Q. As predicted by the standard Q-theory of investment, all relevant information should affect investment through Q in a perfect world. However, it is difficult to meet the assumptions of the standard Q-theory in reality. There may be some variables that affect investment apart

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3 For a direct tackling of measurement errors in Q from econometric point of view, see Erickson and Whited (1997).

4 For more explanations of the unsatisfactory performance of the empirical Q model of investment, see e.g. Abel and Blanchard (1986), Gilehrist and Himmelberg (1995), Chirinko (1986, 1993), Hayashi and Inoue (1991), Schaller and Geogoutsos (1990), and Schaller (1990).
from Q. For example, Ferderer (1993a) shows that the Q-model of investment improves considerably when different uncertainty measures are added to the standard Q-model of investment. This conclusion, however, contrasts with the evidence in Leahy and Whited (1996). They find that uncertainty affects investment mainly through Q.

This paper contributes to the small number of empirical studies in which it is examined how uncertainty affects corporate investment. A structural Q-type investment model is derived, which contains the information on the uncertainty effects of random variables that affect future profitability of firms. Empirical tests are based on a panel of 82 Dutch firms in the period of 1984-1995. We examine whether uncertainty affects corporate investment through Q, or apart from Q. In other words, we assess whether the performance of the Q-model of investment will be improved by including uncertainty factors in the Q-investment equation. We come up with results which show that the volatility of profits and the volatility of the interest rate are the active factors that affect investment apart from Q. Moreover, the presence of uncertainty factors in the Q-investment equation changes the structural parameters of the Q-model of investment. Some uncertainty measures that are significant in the Q-investment equation enhance the explanatory power of Q. The results hold not only for the entire sample of firms, but also for sub-groups like small firms and highly indebted firms. We find that severer uncertainty effects are associated with more likely financial distress by comparing uncertainty effects between small and large, highly and less indebted firms. The partitioning of the sample is based on the degree in which firms can communicate information with outside lenders, and hence are confronted with financial constraints. Hence, the results for the sub-groups of firms provide some indirect evidence on the interaction between uncertainty and capital market imperfections.

The remainder of the paper is organized as follows: Section 2 derives a structural Q-type investment model, which contains uncertainty factors in the Q-investment
equation. Section 3 is on data arrangement. Empirical evidence is discussed in section 4. Section 5 summarizes and concludes the paper.

2 THE Q MODEL WITH UNCERTAINTY

Suppose a firm maximizes the value of the firm over time by choosing the optimal investment trajectory. This requires us to define the value function of the firm. In a world with uncertainty, the value of the firm is not equivalent to the expected discounted present value of the future profit stream generated by the firm. The difference between the two is the measure of the cost of risk. The regular objective function of the firm that is widely used in deriving the standard Q-model of investment is equation (1), in which uncertainty is only represented by the expectation operator. In the profit identity equation (3), no uncertainty costs that are associated with future profit stream are taken into account.

\[
\text{Max } V_0 = E_0 \int_0^\infty \pi_t e^{-rt} dt \\
\text{s.t. } K_t = I_t - \delta K_t
\]

and \[\pi_t \equiv p_t f(K_t, L_t) - w_t L_t - p_t A(I_t, K_t) - p_t^L I_t\]

Where \(V_0\) is the discounted present value of the firm at time \(t = 0\). \(E_0\) is the expectation operator based on the information available at time \(t = 0\). \(r\) is the constant discount rate faced by the firm, which is measured in real terms. \(f(K_t, L_t)\) is the production function. \(\pi_t, K_t, L_t\), and \(I_t\) are the nominal profit, the capital stock, the labor input, and the gross investment of the firm at time \(t\).
respectively. $\delta$ is the constant depreciation rate of capital. $w_t$, $p_t$, and $p^t$ are the nominal wage rate, the output price, and the price of capital goods, respectively. $A(I_t, K_t)$ is the internal convex cost function of adjusting the capital stock.

To derive the Q model of investment with uncertainty, we first need to derive the dynamic objective function for the firm under uncertainty. It is based on Nickell (1978). We start with the utility function of the individuals who make portfolio decisions. Suppose that a stockholder $i$ chooses a portfolio of holding a fraction of the stock of individual firms and net borrowing. His utility function is assumed to be the mean-variance valuation utility, which takes the form as $U_i(cf_i, h_i)$, where $cf_i$ is the expected cash flow generated by his asset portfolio and $h_i$ is the variance of this cash flow. $\frac{\partial U_i}{\partial cf_i} > 0$, $\frac{\partial U_i}{\partial h_i} < 0$. Let $\rho_{ij}$ be the fraction of the stock of firm $j$ held by individual $i$ and let $b_i$ be his net borrowing. Assume that stockholders are homogeneous in the sense that they have the same expectations on firm’s profitability. If $R^*_j$ is the random variable that represents the total return paid to the stockholders of firm $j$, $E(R^*_j) = R_j$, $Var(R^*_j) = \sigma_{jj}$, and $Cov(R^*_j, R^*_k) = \sigma_{jk}$, then we have:

$$cf_i = \sum_j \rho_{ij} R_j - (1 + r^f) b_i$$  \hspace{1cm} (4)$$

and

$$h_i = \sum_j \sum_k \rho_{ij} \rho_{ik} \sigma_{jk}$$  \hspace{1cm} (5)$$

This idea was put forward by Stevens (1974) and Nickell (1978).
Where \( r^f \) is the risk-free rate of interest. The optimization problem for stockholder \( i \) can be specified as follows:

\[
\text{Max } U_i(cf_i, h_i) \\
\text{s.t } \sum_j \rho_{ij} V_j - b_i = W_i
\]  

(6)

where \( W_i \) is the initial wealth of individual \( i \). \( V_j \) is the market value of firm \( j \) at the time of decision making. The necessary condition for the problem could be obtained by solving the Lagrangian with respect to \( \rho_{ij} \):

\[
\frac{\partial U_i}{\partial c_{f_i}} [R_j - (1 + r^f)V_j] + 2 \frac{\partial U_i}{\partial h_i} \sum_k \lambda_{ik} \sigma_{jk} = 0 \quad \forall \ i, j
\]  

(7)

In equilibrium assuming \( \sum \rho_{ij} = 1, \forall \ j \), the market value of firm \( j \) is:

\[
V_j = \frac{1}{1 + r^f} \left[ R_j - \theta \sum_k \text{Cov}(R^*_j, R^*_k) \right]
\]  

(8)

where \( \theta = \frac{\sum_k R_k - (1 + r^f) \sum_k V_k}{\sum_k \sum_l \sigma_{kl}} \)  

(9)

The numerator of \( \theta \) represents the total current cost of risk and the denominator of \( \theta \) is the total quantity of risk. Therefore, \( \theta \) is the price of risk. It is the
amount that any individual in the market would be prepared to pay to avoid one unit of risk. Notice that it is easy to prove (from equation 7) that $\theta$ is related to the utility function of the agent. Therefore it is related to the measure of risk aversion. However, the measure of risk aversion in this model is not necessary to be specified because of the assumption of the mean-variance valuation utility function. In fact, allowing the second moment of random variables enters into the utility function imposes risk aversion.

Assume that the final return to the investors of firm $j$ is equal to the total dividend paid by firm $j$ plus the value of firm $j$ at the end of the period, that is:

$$R^*_j = D^*_j + V^*_{j,t+1} \quad (10)$$

where superscript * denotes that the variables are random variables. $D^*_j$ is the total dividend paid out by firm $j$ in period $t$. Rewriting equation (8) using equation (10) and adding a time subscript, we obtain:

$$V_j = \frac{1}{1+r^f} \left[ E(D^*_j) + E(V^*_{j,t+1}) - \theta \sum_k Cov(D^*_j, V^*_{j,t+1}) \right] \quad (11)$$

For ease of exposition, we assume that $r^f$ and $\theta$ are deterministic variables. This assumption ensures that all the $V_j$ and hence capital gains are nonstochastic.\(^6\) Since equation (11) holds for all $t$, we have:

$$V_j = \sum_{s=0}^{\infty} \frac{1}{(1+r^f)^{s-t}} \left[ E(D^*_j) - \theta \sum_k Cov(D^*_j, D^*_k) \right] \quad (12)$$
In continuous time:

\[
V_j(0) = \int_0^\infty e^{-\alpha t} \left[ E(D_j^*) - \theta \sum_k Cov(D_j^*, D_k^*) \right] dt
\]  
(13)

In practice, the stockholders of the firm are only concerned with idiosyncratic shocks, i.e. \( \sum_k Cov(D_j^*, D_k^*) = Var(D_j^*) \). If we regard the dividend flow \( D_j^* \) as the random net earnings flow (profit \( \pi_j^* \)) generated by firm \( j \) at time \( t \) and assume that the discount rate of the firm \( r \) is constant and equal to the risk-free rate of interest \( r_f \), then the value function of the firm becomes:

\[
V_j(0) = \int_0^\infty e^{-\alpha t} \left[ E_0(\pi_j^*) - \theta Var(\pi_j^*) \right] dt
\]  
(14)

where \( Var(\pi_j^*) \) is the variance of profits in period \( t \), which is the measure of the quantity of the risk that is associated with the future income stream. Equation (14) states that the value of the firm is equal to the expected present value of the future income stream generated by the firm less the total cost of the risk associated with that particular income stream.\(^7\)

Below we derive the Q-model of investment with uncertainty using the objective function equation (14) derived based on Nickell (1978). Using this objective function is implicitly based on the assumption that there are no agency costs between the stockholders and the managers of the firm. The managers of the firm

\(^6\) For the general case that the risk-free rate of interest \( r_f \) and the market price of risk \( \theta \) are random variables, see Stevens (1974).

\(^7\) For more details on the derivation of the dynamic objective function for firms under uncertainty, see Nickell (1978), p160-163, and his Appendix, proposition 2.
act in the interest of shareholders. Unlike Nickell (1978), we measure the amount of risk by introducing a cost function of uncertainty instead of using the variance of profits directly. In this paper we assume that the loss incurred from uncertainty is a linear function of the volatility of the profit stream generated by the firm. The volatility of profits is measured by the standard deviation of profits. It is also assumed that the loss due to uncertainty is related linearly to both firm size and the size of investment. The bigger the investment project, the more serious the concern for uncertainty effects. In addition, large firms normally can more easily accommodate the loss due to uncertainty than small firms because of diversification within the firm. If we use the value of the capital stock to proxy firm size, the cost function of uncertainty can be expressed as:

\[ UC_t = SD(\pi_t) \left[ \gamma_1 p_t^I K_t + \gamma_2 p_t^I I_t \right] \] (15)

Where \( UC_t \) is the loss due to uncertainty at time \( t \). \( \gamma_1, \gamma_2 \) are parameters and \( \gamma_1 < 0, \gamma_2 > 0 \). \( SD(\pi_t) \) is the standard deviation of profits at time \( t \).

We denote uncertainty by the volatility of any random variable that affects the profitability of the firm. We believe that it is such volatility that often causes the expected profit to deviate from its realizations. We are concerned with idiosyncratic uncertainty. Shocks are assumed to be exogenous. If the firm faces high uncertainty, it is required to put more effort in collecting relevant information than it does in the case of certainty. Another example of the loss due to uncertainty is that high volatility of demand may result in the production line to be idle at least partially for some time. More formally, if capital investment is

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\( ^8 \) This is generally true even without consideration of financial positions of the firm, especially for European firms. In the empirical analysis, we compare the heterogeneity of uncertainty effects between small and large firms from the point of view of the sensitivity of investment to uncertainty rather than the possible loss incurred from uncertainty.
irreversible, uncertainty leads the firm to delay investment until new information arrives. Waiting to invest has two consequences. On the one hand, waiting generates the loss of operating profits; in some cases, it may cause the loss of consumers forever. The effect of uncertainty on the value of the firm in this respect is to reduce the firm’s incentive to wait in any case. On the other hand, however, waiting has the value itself if we regard the investment project as a call option. Hence, uncertainty generates an option value of waiting. The effect of uncertainty in this respect is to stimulate the firm to delay investment. The higher the uncertainty, the stronger the incentive to wait. The net effect of uncertainty on the value of the firm is ambiguous if the two opposite effects are combined. Moreover, the impact of uncertainty on a firm’s profitability also depends on the firm’s attitude towards risk. A risk-averse firm does not like uncertainty at all, while higher uncertainty is regarded as a higher potential profitability for the firm who is a risk-lover. In this paper, we assume that $\theta$ in the objective function of the firm (equation (14)) is positive. This is equivalent to assuming that the stockholders of the firm are risk-averse. This implies that we actually impose a negative effect of uncertainty on investment in our investment model.

Inserting (3) into (14) and using equation (15) to measure the quantity of uncertainty, the objective function becomes:

$$V_0 = \int_0^{\infty} \left[ E_0 \left[ p_t F(K_t, L_t) - w_t L_t - p_t A(I_t, K_t) - p^I_t I_t \right] 
- \theta SD(\pi_t) (\gamma_1 p^I_t K_t + \gamma_2 p^I_t I_t) e^{-\alpha} \right] dt$$

(16)

Taking into account of the capital accumulation identity (equation (3)), we set up the Hamiltonian function:

$$H_t = \left[ E_0 \left[ p_t F(K_t, L_t) - w_t L_t - p_t A(I_t, K_t) - p^I_t I_t \right] 
- \theta SD(\pi_t) (\gamma_1 p^I_t K_t + \gamma_2 p^I_t I_t) \right] e^{-\alpha}$$
\[ + \lambda_i (I_i - \delta K_i) \]
\[ = \left\{ E_0 \left[ p_i F(K_i, I_i) - w_i L_i - p_i A(I_i, K_i) - p_i' I_i \right] ight. 
\[ - \theta SD (\pi_i) \left[ \gamma_1 p_i' K_i + \gamma_2 p_i' I_i \right] + \mu_i (I_i - \delta K_i) e^{-\eta} \] (18)

where \( \lambda_i \equiv \mu_i e^{-\eta} \). It represents the slack parameter or the shadow price of capital.

As we mentioned above, shocks are assumed to be exogenous, so the volatility of profits is independent of control variables. The total quantity of uncertainty is a function of investment, in which the size effect of the investment project is multiplied by the volatility of profits. Assume that the managers of the firm perfectly foresee endogenous variables based on the information available to them at the time when they make investment decisions. Therefore the expectation operator can be dropped from the problem.

The first order condition with respect to \( I_i \) gives:

\[- p_i \frac{\partial A(I_i, K_i)}{\partial I_i} - p_i' - \theta \gamma_2 SD(\pi_i) p_i' + \mu_i = 0 \] (19)

To obtain the Q-type investment model, we further assume that the price of capital goods equals the price of consumption goods \( (p_i' = p_i) \). Rearranging equation (19), we have:

\[ 1 + \frac{\frac{\partial A(I_i, K_i)}{\partial I_i}}{\theta \gamma_2 SD(\pi_i)} = \frac{\mu_i}{p_i} \] (20)
By definition the right hand side of equation (20) is marginal $Q$: the ratio of the shadow price to the market price of a unit of capital. Therefore, equation (20) is equivalent to:

$$1 + \frac{\partial A(I_t, K_t)}{\partial I_t} + \theta \gamma_2 SD(\pi_t) = Q_t$$  \hspace{1cm} (21)

We assume that the adjustment cost function takes the general quadratic form given by:

$$A(I_t, K_t) = \alpha_1 I_t + \alpha_2 \frac{I_t^2}{K_t}$$  \hspace{1cm} (22)

Where $\alpha_1, \alpha_2$ are constants and $\alpha_2 > 0$. Then,

$$\frac{\partial A(I_t, K_t)}{\partial I_t} = \alpha_1 + 2\alpha_2 \frac{I_t}{K_t}$$  \hspace{1cm} (23)

Using (23) in (21) and rearranging it, we get:

$$\frac{I_t}{K_t} = -\frac{1 + \alpha_1}{2\alpha_2} + \frac{1}{2\alpha_2} Q_t - \frac{\theta \gamma_2}{2\alpha_2} SD(\pi_t)$$  \hspace{1cm} (24)

Redefining parameters in (24):

$$\frac{I_t}{K_t} = \beta_1 + \beta_2 Q_t + \beta_3 SD(\pi_t) + \epsilon_t$$  \hspace{1cm} (25)
Where $\varepsilon_i$ is the error term. The sign of $\beta_1$ is unknown, $\beta_2 > 0$ since $\alpha_2 > 0$ and $\beta_3 < 0$ since we assume $\theta > 0$ and $\gamma > 0$.

The difference between equation (25) and the standard Q-model of investment is the presence of the uncertainty factor in the Q-investment equation, which is represented by the standard deviation of profits.

We proceed with our empirical analysis as follows. First, we estimate equation (25) without any uncertainty measure for the whole sample in order to obtain the benchmark of the empirical performance of the standard Q-model of investment thereby assuming that the market price of risk ($\theta$) is zero. Secondly, we estimate the Q-model with uncertainty (equation (25)) for the whole sample. Special attention will be paid to the robustness of the structural parameters of the Q-model. Thirdly, we perform the same regressions for subsamples (small vs. large firms; highly indebted vs. less indebted firms) to obtain some insights into the interaction between capital market imperfections and uncertainty effects. We believe that the wedge between external financing and internal financing depends on the probability of the default of the firm. The probability of the default of the firm depends on the volatility of the profit stream generated by the firm. Future profitability of the firm is influenced by the changes in external factors, such as the demand, the output price, the labor cost, the interest rate, etc. Consequently, the random variables that are related to profits should matter for the financial condition of the firm. Since higher probability of default is associated with higher degree of uncertainty facing the firm, severe uncertainty is expected to aggravate the financial constraints suffered by the firm, and vice versa. In the literature a large amount of evidence supports that small firms and highly indebted firms are the firms that are more likely to come under the pressure of financial distress due to imperfect capital markets. We are concerned with the differences in uncertainty effects between such interesting subgroups of firms and their counterparts. The improvement of the explanatory power of Q from the subsample regressions could
be taken as the robustness test on the evidence obtained from the whole sample regressions. We add firm-fixed effects and time effects into equation (25) in our empirical tests.

3 DATA ARRANGEMENT

The dataset concerns a balanced panel of 82 listed Dutch firms in the period of 1984-1995. It was taken from the publication Jaarboek van Nederlandse Ondernemingen. Due to the construction of uncertainty measures, we lost 3 years of observations of all variables. One year’s observation was lost due to the first order autoregression and the other two were lost due to calculating moving average standard deviations. As it turns out, our empirical test covers a sample from 1987 to 1995.

Table 1 presents descriptive statistics of some selected variables for our sample. The table shows that Tobin’s Q is relatively stable across firms. However other variables differ considerably across different sub-samples. The mean and the median value of the capital stock, cash flow, sales, and debt are larger for large firms and less indebted firms as compared to their counterparts. The differences in these variables are especially large between large and small firms. Notice that the mean (median) value of the capital stock for less indebted firms is 17.21 (7.84) times that of highly indebted firms. While the mean (median) value of debt for less indebted firms is only 4.97 (1.67) times that of highly indebted firms. This implies that interests burden of highly indebted firms is considerably higher than that of less indebted firms. This consequence can be seen from the difference in the value of cash flow between highly and less indebted firms. The mean (median) value of cash flow for less indebted firms is 9.95 (3.84) times that for highly indebted firms. In Table 1, Tobin’s Q is average Q. In our empirical analysis, we use average Q to proxy marginal Q as usual. This means that the tests in the paper
are, to some extent, joint tests on the investment model we are proposing in section 2 together with measurement errors of Q. Due to data restrictions, we are not able to avoid measurement problems of Q, this requires our care in interpreting estimation results in section 4.

One of the key issues of empirically investigating the effect of uncertainty on investment is the measurement of uncertainty no matter which investment model is used. Before proceeding with our empirical tests, we first need to measure the volatility of uncertainty variables.

3.1 The Measurement of Uncertainty

Volatility characterizes the ups and downs of a time series. There are many alternative measures of the volatility of time series. The most often used statistic is the standard deviation. The standard deviation demonstrates how much the underlying time series deviates from its mean values. In most empirical studies on the effect of uncertainty on investment, the standard deviation is chosen as the measure of the volatility for the underlying variable. The differences in the construction of uncertainty measures are in the ways by which standard deviations are calculated. For discrete time series, three methods are often used: (1) the constructed variance is the variance of the unpredictable part of a stochastic process (Aizenman and Marion 1993, Ghosal 1995b, Ghosal and Loungani 1996, Ghosal and Loungani 1997, Peeters 1997). (2) the conditional variance is estimated from the Generalized AutoRegressive Conditional Heteroskedastic (GARCH)-type model. (Huizinga 1993, Episcopos 1995, Price 1995, 1996). (3) the variance is derived from Survey Data (Guiso and Parigi 1996, Ferderer 1993b, Pattillo 1998). For continuous time observations, the variance could be estimated from stochastic volatility models, such as the geometric Brownian motion (Pindyck and Solimano 1993, Caballero and Pindyck 1996).
Using the variance of the unpredictable part of a stochastic process as the measure of uncertainty requires us to set up the process that generates the predictable part of the stochastic process. In empirical applications we can observe different kind of forecasting rules to predict the predictable part of random variables. Once the Markov property of the series is assumed, all forms of autoregressive forecasting equations can be used. However, this method is based on the assumption that either the unconditional variance of a random variable is constant or the conditional variance converges to a constant term, which is not always the case in reality. In theory, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH)-type modeling of volatility can offer a more precise measure of uncertainty in the sense that it allows the time dependence of the second moment of random variables. Although there is no difference in the conditional mean between the two approaches, the difference in the conditional variance may matter for investigating the effect of uncertainty on investment. However, the application of the GARCH-type model to measure volatility requires high frequency observations and longer time series. This may limit its applications in the field of investment. In general, the variances constructed from the unpredictable part of a stochastic process, the GARCH-type modeling of volatility, and from the geometric Brownian motion are all based on the assumption that expectations on future variables are based on past trends and on the information set available to the firm rather than to individual agents. Strictly speaking, these uncertainty measures are not able to carry individual agents’ perception of risk, conditional on their own information set. The advantage of using survey data to construct the measure of uncertainty is that the data directly carries the information on agents’ expectations on future variables. In the present study, we follow the method of constructing the variance of the unpredictable part of a stochastic process. The choice of the technique for constructing uncertainty measures is mainly based on data restrictions. This method of measuring uncertainty can be summarized as follows:
(1) Setting up the forecasting equation for the underlying uncertainty variable.

(2) Estimating the forecasting equation to get the unpredictable part of the fluctuations of that variable, i.e., the estimated residuals.

(3) Computing the conditional standard deviations of the estimated residuals as the uncertainty measure of the concerned variable.

More specifically, we assume that the underlying stochastic variable follows a first-order autoregressive process, which is given below;

\[ Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \nu_t \]  

(26)

where \( Y_t \) represents the underlying uncertainty variable, which is assumed to be stochastic with a mean-preserving spread in \( Y_t \). \( \nu_t \) is the unpredictable part of the fluctuations of the underlying variable, in which we are interested. We estimated equation (26) for each firm by ordinary least squares and saved the estimated residuals. To facilitate panel analysis, we calculated 3-year moving average standard deviations of the estimated residuals for each firm to construct the series of the uncertainty measure. We dated the computed 3-year moving standard deviations in the final year of each 3-year overlapping period. It is the measure of uncertainty for that year. Since the uncertainty variables we consider in this paper are likely to be generated by relatively short-term forecasting processes, we believe that the uncertainty measures constructed by our method have the power to demonstrate the volatility of that variable.

### 3.2 The Partitioning of the Sample

The most often used proxy for capital market imperfections is firm size. It is believed that large firms have fewer difficulties in accessing external capital markets than small firms. Large firms normally have a longer history and a good reputation in cooperating with their upstream and downstream cooperators. They also have stronger links with financial intermediaries. They therefore have fewer information problems than small
We first split our sample by firm size. We chose the average capital stock over the whole sample period as the proxy for firm size. The top 42 firms are large firms and the other 40 firms are small firms. Some empirical research in the effect of uncertainty on investment find strong evidence that firm size is able to ameliorate uncertainty effects (Ghosal 1991, Ghosal and Loungani 1997, Peeters 1997, Pindyck 1986). We expect that small firms show relatively stronger uncertainty effects than large firms. If this is the case, it can be argued that the imperfection of capital markets is one possible channel through which uncertainty might affect investment. This in turn suggests that there exist an interaction between capital market imperfections and uncertainty.

In addition to size splitting, we chose debt as the second proxy for capital market imperfections. Debt is an important financial policy variable that indicates the financial position of the firm (Whited 1992). However, there is possible ambiguity using debt splitting. High debt may signal either a good track record in getting loans or being fully loan dependent. Using the same dataset, we find that highly indebted Dutch firms are more likely to face liquidity constraints in our previous study that investigates inventory behavior (Bo, Kuper, Lensink, and Sterken 1998). In a recent study, Kaplan and Zingales (1997) also find that the debt to capital ratio increases with the degree of the financial constraints faced by the firm. Therefore, we define highly indebted firms as the firms that have more financial problems. We calculated the average debt to capital ratio for each firm over the sample period. Highly indebted firms include the top one-thirds firms in the whole sample. The lowest one-thirds firms are included in the less indebted group. We ignore one firm that has an extreme high value of the debt to capital ratio from the highly indebted group. The highly indebted group contains 26 firms. The less indebted group consists of 27 firms. We test whether capital market imperfections and uncertainty effects interact by checking the differences.

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9 In the literature, many studies have proved that firm size is a useful proxy for the accessibility of external capital markets. For example, Fazzari, et.al (1988); Gertler and Gilchrist (1994); Ramey (1993); Calomiris and Hubbard (1990); Oliner and Rudebusch (1992, 1996); Gilchrist and Himmelberg (1998).
in uncertainty effects between highly indebted firms and less indebted firms. Peeters (1997) finds evidence that low-leverage is associated with larger uncertainty effects for both Spanish and Belgian firms.

4 RESULTS

One objective of the paper is to check whether uncertainty affects corporate investment in the Q-model. To obtain this insight, we are not restricted by the volatility of profits, which was directly given by the model (equation 25). We are also interested in profit-related variables. Since profit is often disrupted by movements in other random variables, such as the demand, the input price, and the interest rate. We are concerned with the sensitivity of profits (and the volatility of profits) to relevant random variables. To select profit–related variables we regressed the current value of profit $\pi_t$, and the volatility of profits $SD(\pi_t)$ separately on the lagged value of sales $S_{t-1}$, the lagged value of the nominal interest rate $R_{t-1}$, and the lagged value of investment tax credit $G_{t-1}$. We found that all these variables except the investment tax credit are highly significant in explaining both profit and the changes in profit for our whole sample. After controlling for the lagged value of profit and the lagged value of the volatility of profits, we obtained similar results. Table 2 shows the results of fixed-effect weighted ordinary least square estimations for the whole sample. Considering the general performance of the selected variables, we believe that sales and the nominal interest rate can explain profit and predict the changes in profit. It is plausible that the volatility of these variables should be able to explain investment too. Therefore we constructed measures for the volatility of the selected variables and used these measures one by one in equation (25) to check the performance of the Q model of investment.

Table 3 reports Two-Stage Least Squares (TSLS) estimation results for the whole sample and all sub-samples. Applying the instrumental estimation is
motivated by our concern for the endogeneity of Q in the investment equation. We use the lagged-one Q and the lagged-two Q as the instruments for Q. Table 3 reveals three main observations. First, Q does not carry all the information relevant to a firm’s investment decisions. Some aspects of uncertainty affect investment apart from Q. The volatility of profits \( SD(\pi) \) is highly significant with a negative sign in all cases except for less indebted firms. The volatility of the interest rate \( SD(r) \) is highly significant with a negative sign for the whole sample and highly indebted firms. The striking result is that \( SD(r) \) strongly outperforms Q in the regression for highly indebted firms. The volatility of sales \( SD(s) \) has no statistically significant effects on investment except for large firms. Secondly, the presence of uncertainty measures changes the structural parameters of the Q model of investment. Table 3 demonstrates that the presence of the volatility measure of profit \( SD(\pi) \) increases the statistically explanatory strength of Q for both the whole sample and small firms. This is consistent with Ferderer (1993a). It suggests that uncertainty factors are important in explaining investment in a Q-model of investment. Unfortunately, there is no study available to date that explicitly investigates the sources of the unsatisfactory empirical performance of the standard Q-model of investment from the economics of uncertainty point of view. Our evidence shows that one of the possible sources of the unsatisfactory empirical performance of the standard Q-model of investment may be the ignoring of the market price of risk \( \theta \) in the Q-investment equation. Finally, compared to the whole sample estimations and to the regressions for large firms and less indebted firms, it turns out that uncertainty effects are larger for small firms and for highly indebted firms as long as uncertainty measures have explanatory power in the investment equation. Moreover, the effect of the interest rate uncertainty has significant explanatory power and it strongly outperforms Q for highly indebted firms. The relevance of the interest rate uncertainty for highly
indebted firms is reasonable. Since a large fraction of external financing is debt for highly indebted firms, the fluctuations of the interest rate are expected to have a serious impact on investment for such firms.

The difficulty arises when we compare the heterogeneity of uncertainty effects between small and large firms, highly and less indebted firms based on the evidence in Table 3. The Q-model of investment does not apply to some subsamples in our dataset. The estimated coefficient of Q for the whole sample is almost always significant and has the expected sign across different regressions. In subsample regressions, it turns out that Q remains highly significant and has a positive sign for small firms and highly indebted firms that we defined as the likely financially constrained firms. However, Q is not significant for both large firms and less indebted firms. In addition, it has wrong sign for large firms. It shows that financially unconstrained firms in our dataset have no incentive to respond to Q in making their investment decisions.\footnote{To check whether large (less indebted) firms react to Q more slowly than small (highly indebted) firms, we tested the sensitivity of investment of large firms and less indebted firms separately to the lagged values of Q. Neither of the lagged-one Q, the lagged-two Q, and the lagged-three Q is significant.} The insensitivity of investment to Q could be explained by the fact that agency costs between the managers and the shareholders for large firms and less indebted firms are higher. The managers of these firms do not seriously care about the stock market valuation of the firm, they respond sensitively to their own perceptions of investment fundamentals, such as the growth of sales, the size of the firm (Blanchard et al 1993, Morck et al 1990, and Samuel 1996). The higher agency costs between the managers and the shareholders of these firms invalidates the use of the objective function (14) that we used in deriving the Q-model with uncertainty for these two groups of firms. On the other hand, recent research on the Q-theory of investment find evidence that the relationship between investment and Q is not linear if the assumption of the quadratic adjustment cost function is
relaxed (Eberly 1997, Barnett and Sakellaris 1998). There exists an interval that is determined by the trigger values of Q, in which the sensitivity of investment to Q is zero. Since the issue of the adjustment cost function is beyond the scope of this paper, we interpret the insensitivity of investment to Q from the point of view of agency costs to match the model we derived in section 2.

However, we need to compare the differences in uncertainty effects between small and large firms, highly and less indebted firms to obtain some insights into the interdependence between uncertainty effects on investment and capital market imperfections. To make an effort in this direction, we performed an additional test. Sticking with the structural model we derived (equation 25), we used the growth rate of sales to proxy investment fundamentals instead of Q in estimations. We expect that all sub-groups of firms in our sample respond to the fundamentals of investment, although some of them do not respond to Q. Table 4 reports the fixed effect estimations of equation (25) with the growth rate of sales replacing Q for all subdivisions of firms. Notice that the rate of growth in sales, as an indicator of investment fundamentals, is highly significant with a positive sign in all cases as we are expecting. We obtained similar results as that in Table 3 with respect to the effect of uncertainty as well as the heterogeneity of uncertainty effects across subsamples. In fact the results in Table 4 provide the robustness tests of the results in Table 3.\textsuperscript{11} Therefore, our evidence shows that Dutch small, highly indebted firms are more sensitive to uncertainty than large, less indebted firms. The result provides some indirect evidence that capital market imperfections aggravate uncertainty effects on investment. The finding that severe uncertainty effects are associated with more likely financial distress is consistent with some other studies in the literature. Guiso and Parigi (1996), for instance,

\textsuperscript{11} We also tried the ratio of sales to the capital stock as the proxy for the fundamentals of investment. Surprisingly, this proxy is not significant for small, less indebted firms. However, the estimate results prove the same qualitative conclusions regarding the effects of uncertainty based on the results in Table 3 and Table 4.
find that the magnitude of the estimated coefficient of demand uncertainty decreases when an indicator of access to credit is added to the investment model. Their evidence indicates that financial constraints lead to more severe demand uncertainty effects on investment. Ghosal and Loungani (1997) use firm size as the proxy for the accessibility of external financing to split the sample into small-firm-dominated industries and large-firm-dominated industries. They find evidence that profit uncertainty is larger for small-firm-dominated industries than that for large-firm-dominated industries. Since their splitting of the sample is explicitly based on the degree in which firms can communicate information with outside lenders, their result proves that there exists an interaction between uncertainty effects and capital market imperfections. Ghosal (1991), Pindyck (1986) also show that the effects of uncertainty on investment are smaller for larger firms. Since larger firms are the typical firms that have fewer problems in obtaining external capital, these studies strongly suggest that investment studies should consider the interaction between capital market imperfections and uncertainty.

Our study provides evidence that the sign between investment and uncertainty is negative. The negative effect of uncertainty on investment is in line with either the irreversibility approach or the financial constraint hypothesis or both. In theory they all predict the negative uncertainty effect on investment. Since our evidence shows that severe uncertainty effects are associated with the higher degree of financial constraints faced by the firm, we attribute the negative uncertainty effect to the role that is played by capital market imperfections. High uncertainty faced by the firm exaggerates the asymmetric information problem and widens the wedge between external financing and internal financing, which causes the firm to

\[\text{12 For the link between irreversibility and uncertainty effects, see Bernanke (1983); Bertola (1987); Dixit (1989); Pindyck (1991); Caballero (1991); and Dixit and Pindyck (1994). For the link between financial constraints and uncertainty, see Mackie-Mason (1990); Greenwald and Stiglitz (1990); Greenwald, Stiglitz and Weiss (1984); Stiglitz and Weiss (1981); and Ghosal and Loungani (1997).}\]
have less access to external capital markets. As a result it discourages corporate investment.

To further prove the changes in the structural parameters of the Q-model of investment after uncertainty factors are taken into account, we tested the hypothesis $H_0: \beta_2^{\text{standard}} = \beta_2^{\text{uncertainty}}$ in order to determine whether the magnitudes of the estimated coefficients of Q were statistically different between the standard Q-model and the Q-model with uncertainty. We compared the sum of squared residuals of the Q-model with uncertainty under the restriction of $\beta_2^{\text{uncertainty}} = \beta_2^{\text{standard}}$ with the sum of squared residuals of the standard Q-model using the F distribution. More specifically, we estimated the standard Q-investment equation to get the estimated coefficient of Q: $\beta_2^{\text{standard}}$, then we let the parameter in front of Q in the Q-model with uncertainty (equation 25) equal $\beta_2^{\text{standard}}$ in estimating the Q-investment equation with uncertainty (equation 25), that is: $\beta_2^{\text{uncertainty}} = \beta_2^{\text{standard}}$. In this way, we obtained the estimated coefficient of uncertainty measure $\beta_2$ in equation (25). By estimating these two models, we computed the sum of squared residuals for each of the regressions and calculated the F-statistics. Table 5 reports the calculated values of F-statistics. For each pair of comparisons in Table 5, the value of F-statistics is greater than the critical value of the F distribution at both 5% and 1% levels. Therefore we can consistently reject the null hypothesis that the estimated coefficient of Q from the standard Q-model equals the estimated coefficient of Q from the Q-model with uncertainty. This result supports the idea that uncertainty factors do matter in the Q-model of investment.
5 CONCLUSIONS

This paper provides some evidence that uncertainty is important in explaining Dutch corporate investment within the Q-model of investment. The standard Q-model of investment incorporates the expectations on future profitability of the firm. In addition to the standard model, there might be other factors that interact with uncertainty effects, such as firm size, irreversibility, market competition, factor substitutability, and the financial policies of the firm.

This study contributes to empirical research on the effect of uncertainty on investment from two aspects. First, we investigated whether uncertainty factors affect corporate investment within the Q framework. As predicted by the standard Q-theory of investment, Q should carry all the information that is relevant to a firm’s investment decisions. Our evidence shows that the volatility of profits and the volatility of the interest rate are the active factors that affect investment apart from Q. Moreover, the presence of uncertainty measures in the Q-investment equation changes the structural parameters of the Q-model of investment. Some significant uncertainty measures enhance the statistically explanatory power of Q. This provides one possible explanation that the unsatisfactory empirical performance of the standard-Q model of investment may be due to the omission of uncertainty considerations. Secondly, we incorporate uncertainty and capital market imperfections in the Q-model of investment. Dutch firm-level evidence shows that severe uncertainty effects are associated with more serious financial distress faced by the firm. This indirectly implies that one possible channel through which uncertainty might affect corporate investment is capital market
imperfection. The negative uncertainty effect on investment found in this paper is in line with what is predicted by the financial constraint hypothesis.

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Stevens, G.V.G. (1974) On the Impact of Uncertainty on the Value and
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319-336
Information. American Economic Review 71, 393-410
Whited, T. M. (1992) Debt, Liquidity Constraints, and Corporate Investment:
Evidence from Panel Data. The Journal of Finance 4, 1425-1460
Table 1  Descriptive Statistics: 1984-1995  
(unit: 10^6 Guilders )

<table>
<thead>
<tr>
<th></th>
<th>Capital Stock</th>
<th>Cash Flow</th>
<th>Sales</th>
<th>Debt</th>
<th>Tobin's Q</th>
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<tr>
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<td>Median</td>
<td>Mean</td>
<td>Median</td>
<td>Mean</td>
</tr>
<tr>
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<td>322.21</td>
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<td>Large Firms</td>
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<td>454.01</td>
<td>611.68</td>
<td>122.27</td>
<td>7467.74</td>
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<td>Small Firms</td>
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<td>18.26</td>
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<td>Low-Debt Firms</td>
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<td>429.74</td>
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<td>High-Debt Firms</td>
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<td>43.19</td>
<td>19.02</td>
<td>1010.07</td>
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</tbody>
</table>

(1) Data source: Own calculations from dataset taken from *Jaarboek van Nederlandse Ondernemingen*
Table 2  The Selection of Uncertainty Variables

<table>
<thead>
<tr>
<th>Regressor</th>
<th>Coefficient</th>
<th>t-Statistic</th>
<th>Regressor</th>
<th>Coefficient</th>
<th>t-Statistic</th>
</tr>
</thead>
<tbody>
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<td>$S_{t-1}$</td>
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<td>371.9572</td>
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<td>$G_{t-1}$</td>
<td>-0.3088</td>
<td>-2.9496</td>
<td>$G_{t-1}$</td>
<td>-0.0064</td>
<td>-0.1605</td>
</tr>
</tbody>
</table>

R-squared 0.9006  R-squared 0.5872

<table>
<thead>
<tr>
<th>Regressor</th>
<th>Coefficient</th>
<th>t-Statistic</th>
<th>Regressor</th>
<th>Coefficient</th>
<th>t-Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_{t-1}$</td>
<td>0.1640</td>
<td>6.2501</td>
<td>$SD(\pi_{t-1})$</td>
<td>0.6480</td>
<td>19.7398</td>
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<tr>
<td>$S_{t-1}$</td>
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<tr>
<td>$G_{t-1}$</td>
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<td>0.7445</td>
<td>$G_{t-1}$</td>
<td>0.0061</td>
<td>0.1291</td>
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</table>

R-squared 0.9076  R-squared 0.6912

(2) Data source: Own calculations from dataset taken from *Jaarboek van Nederlandse Ondernemingen*
(3) Fixed effect weighted Ordinary Least Squares Estimation for the whole sample
Table 3  Two-Stage Least Squares Estimations

\[ \frac{L_t}{K_t} = \beta_1 + \beta_2 Q_t + \beta_3 SD(\pi_t) + \epsilon_t \]

| Regressors | Whole Sample | Large Firms | Small Firms | Low-Debt Firms | High-Debt Firms |
|------------|--------------|-------------|-------------|----------------|----------------|--------------------------------------|
|            | Coefficien t-Statistic | Coefficien t-Statistic | Coefficien t-Statistic | Coefficien t-Statistic | Coefficien t-Statistic | Coefficien t-Statistic |
| Q          | 0.054        | 2.4009      | 0.0088      | 0.2389         | 0.0793         | 2.7689     | 0.0261          | 0.8337          | 0.1038          | 2.7             |
| Q          | 0.0514       | 2.7698      | -0.0035     | -0.1103        | 0.0801         | 3.2321     | 0.0431          | 1.4647          | 0.0655          | 2.26E           |
| SD(\pi_t) | -2.98E-08    | -2.2359     | -2.99E-08   | -2.2142        | -2.23E-06      | -2.2839    | -5.11E-08       | -0.8909         | -1.12E-06       | -2.0C           |
| Q          | 0.0292       | 1.5089      | -0.019      | -0.6007        | 0.0589         | 2.5756     | 0.0288          | 1.005           | 0.0251          | 0.56E           |
| SD(s_t)    | 2.32E-08     | 1.878       | 2.74E-08    | 2.1831         | -3.59E-08      | -0.3863    | 4.28E-08        | 1.8201          | -6.39E-08       | -0.55E          |
| Q          | 0.0428       | 2.041       | -0.0025     | -0.0704        | 0.0721         | 2.3246     | 0.0179          | 0.6051          | 0.0086          | 0.20C           |
| SD(r_t)    | -0.0172      | -2.205      | -0.0105     | -0.7261        | -0.0148        | -1.3871    | 0.0233          | 1.8628          | -0.0424         | -2.667          |

(1) Data source: Own calculations from dataset taken from *Jaarboek van Nederlandse Ondernemingen*
(2) Fixed effect weighted Two-Stage Least Squares Estimation
Table 4 Fixed Effect Estimations:

\[
\frac{I_t}{K_t} = \gamma_1 + \gamma_2 \frac{S_t}{S_{t-1}} + \gamma_3 SD(\pi_t) + e_t
\]

<table>
<thead>
<tr>
<th>Regressors</th>
<th>Large Firms</th>
<th>Small Firms</th>
<th>Low-Debt Firms</th>
<th>High-Debt Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>t-Statistic</td>
<td>Coefficient</td>
<td>t-Statistic</td>
</tr>
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<td>(S_t/S_{t-1})</td>
<td>0.2082</td>
<td>9.8757</td>
<td>0.1975</td>
<td>6.7125</td>
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<td>(S_t/S_{t-1})</td>
<td>0.2082</td>
<td>9.8867</td>
<td>0.1978</td>
<td>6.7649</td>
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<tr>
<td>(SD(\pi_t))</td>
<td>-2.67E-08</td>
<td>-2.2452</td>
<td>-5.90E-06</td>
<td>-2.9255</td>
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<td>(S_t/S_{t-1})</td>
<td>0.2121</td>
<td>9.8543</td>
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<td>(SD(r_t))</td>
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<td>-1.1736</td>
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</table>

(1) Data source: Own calculations from dataset taken from *Jaarboek van Nederlandse Ondernemingen*
(2) Fixed effect cross section weighted Estimations
Table 5  Tests of the Equality of the Estimated Coefficients of Q

<table>
<thead>
<tr>
<th></th>
<th>The Q model with $SD(\pi_1)$</th>
<th>The Q model with $SD(s_1)$</th>
<th>The Q model with $SD(r_1)$</th>
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</thead>
<tbody>
<tr>
<td>Whole Sample:</td>
<td></td>
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<tr>
<td>The Standard Q Model</td>
<td>125.67</td>
<td>124.86</td>
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<td>Small Firms:</td>
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<tr>
<td>The Standard Q Model</td>
<td>76.67</td>
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<td>79.14</td>
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<tr>
<td>High Debt Firms:</td>
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<tr>
<td>The Standard Q Model</td>
<td>38.45</td>
<td>42.52</td>
<td>31.03</td>
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</table>

(1) Data source: Own calculations from dataset taken from *Jaarboek van Nederlandse Ondernemingen*