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Do Firms Wait to Invest? An Empirical Investigation

Hong Bo and Elmer Sterken*

SOM-theme C Coordination and growth in economies

Abstract

The paper tests a standard real options model of investment using a data set of listed Dutch manufacturing firms over the period of 1984-1997. The threshold value that triggers investment is based on the historical distribution of the profit process and the risk-adjusted discount rate of the firm. The system Generalized Method of Moments (GMM) estimates show that Dutch firms are on average concerned with the option values of investment opportunities. We explore the arguments why firms would be confronted with higher investment hurdles.

Key words: Investment threshold, Irreversibility, Option value of waiting

JEL Classification: D81, E22, D92

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1. Introduction

Recent literature pays a lot of attention to the theoretical relation between investment and uncertainty. The traditional criterion for making investment decisions is the Net Present Value (NPV) rule. If the NPV of a project is positive, it should be undertaken; otherwise, the firm will never implement this project. It is in principle a static decision and there is no timing flexibility of investment. Correspondingly, the optimal neoclassical investment rule is: the marginal revenue of capital equals the marginal cost of capital ($MR = MC$). The real options theory of investment assumes that a firm holds call options on the sequence of net returns that is expected to be generated from the investment project (McDonald and Siegel, 1986; Dixit and Pindyck, 1994). According to the real options theory of investment the option value of the investment opportunity should be a component of the marginal revenue of capital, although the general rule ($MR = MC$) does not change. The intuition is that once the firm decides to invest right away, the opportunity of obtaining more information about uncertain variables is lost. It is equivalent to the situation that the firm gives up the right to improve the outcome if necessary. This right is valuable since revising investment decisions is costly.

There are two key assumptions of the real options theory of investment. On the one hand, investment decisions are irreversible.¹ On the other hand, there is timing flexibility of investment. Imperfect competition in product markets or monopoly power is often regarded as the source of timing flexibility of investment decisions. The assumption of irreversibility guarantees the option value to be operative. If the firm can reverse its investment decisions at zero cost and at any time it likes, even with the presence of uncertainty, the delay of investment and the corresponding option are not valuable. However, irreversibility is not always a sufficient condition for a positive option value or equivalently a negative uncertainty effect on investment. Caballerro (1991) proves that only if irreversibility is combined with imperfect competition or decreasing returns to scale or both, uncertainty affects investment negatively.² Following Dixit and Pindyck (1994), it can be shown that the second moments of stochastic variables relevant to the investment decision increase the threshold that triggers investment. Therefore the basic prediction of the real options theory of investment is that uncertainty depresses investment through the threshold effect. Besides this basic prediction, Abel and Eberly

(1999) document that irreversibility may increase the long-run capital stock of the firm due to a hangover effect. Bar-Ilan and Strange (1999) propose that the positive option value may have a positive effect on investment if the intensity of investment is taken into account. To summarize, there is no a clear-cut theoretical prediction with respect to the impact of irreversibility and option values on investment, which implies that the investment-uncertainty relationship relies more heavily on empirical tests.

There are a few empirical papers that construct the investment threshold and test the effect of uncertainty on investment. Pattillo (1998) tests the threshold effect on investment for manufacturing firms in Ghana using survey data. She estimates the investment threshold in a reduced form equation in which the investment trigger is a function of both demand uncertainty and the cost of capital variables. Caballero and Pindyck (1996) and Pindyck and Solimano (1993) calculate the investment threshold by the extreme value of the marginal profitability of capital. They regress the computed threshold on the drift and the standard deviation of the marginal profitability of capital (as a measure of uncertainty) to test the effect of uncertainty on the threshold and on investment. Although the idea of these empirical papers is based on the real options theory of investment, *i.e.* uncertainty directly increases the investment threshold and through the threshold it depresses investment, estimating the threshold within the structure of the real options model of investment is scarce. In this paper, we follow a standard real options model of investment (Dixit and Pindyck, 1994) to construct the threshold value of profits that triggers firm investment. Dutch firm-level panel data is applied to test the predictions of the real options model. We test whether firms wait to invest due to the consideration of opportunity costs of exercising investment options. Moreover, we present an illustration of the role played by irreversibility in causing firms to wait to invest. Asset liquidity and the speed of depreciation of capital goods are employed as indirect proxies for irreversibility to test the association between the delay of investment and the restriction of irreversibility.

Using an unbalanced panel of 77 listed Dutch manufacturing firms during 1984-1997, we find that the sample firms are on average concerned with the option values of investment opportunities in making investment decisions. They intend to wait until the actual profit hits its threshold value. This result confirms the basic prediction of the real options theory of investment. It is natural to explain this result by examining the main assumptions of the standard real options theory of investment. Therefore we investigate

irreversibility and monopolistic competition issues. The association between our proxies for irreversibility and the delay of investment is not supported by the data. There is no convincing evidence that the restriction of irreversibility, as measured by liquid ratio and the speed of depreciation, is an important concern when firms postpone investment. This implies that probably we need better information on for instance the reselling prices of capital goods to proxy for irreversibility. Moreover, if irreversibility is not an effective factor that drives firms to wait to invest, then the existence of waiting behaviour suggests that the sample firms enjoy timing flexibility in arranging their investment. Timing flexibility allows the sample firms to set higher investment hurdles. This result can be explained by the fact that most of the sample firms are large multinational corporations in the Dutch economy, they are in general monopolistic competitors either on a world scale or in domestic industries. We indeed find evidence that market power is associated with severer waiting effects for the sample firms.

The remainder of the paper is organized as follows: in Section 2, we briefly present a standard real options model of investment. Section 3 discusses practical issues. Section 4 explains the choice of proxies for irreversibility. Evidence is discussed in Section 5. Section 6 concludes.

2. A real options model of investment

In this section, we briefly present a standard real options model of investment based on Dixit and Pindyck (1994).³ The full derivation of the model is presented in Appendix A. A risk-averse firm decides whether to start a new capital investment project in the current year. Suppose that the value of the firm is the expected discounted value of future profits that is generated by the investment project. Profits are stochastic due to uncertain operating conditions. The profit process follows a geometric Brownian motion. The threshold value of profits is given by:

$$\pi^* = \frac{\beta}{\beta - 1} (\rho - \mu_\pi) IC_t \tag{1}$$

and

$$\beta = \frac{1}{2} - \frac{\mu_\pi}{\sigma_\pi^2} + \left[\left(\frac{\mu_\pi}{\sigma_\pi^2} - \frac{1}{2} \right)^2 + \frac{2\rho}{\sigma_\pi^2} \right]^{\frac{1}{2}} \quad (2)$$

where β is the positive root of the quadratic equation that is a solution to the characteristic function of the Bellman equation that defines the value of the investment project. μ_π, σ_π^2 are the drift and the variance of the profit process. ρ is the risk-adjusted discount rate of the firm. IC denotes the investment cost. Equation (1) gives the threshold level of profit π^* . $\frac{\beta}{\beta-1}$ is the so called ‘option value multiplier’. Dixit and Pindyck (1994) prove that $\beta > 1$ as long as the risk-adjusted discount rate ρ is greater than the drift of the stochastic variable μ_π .⁴ Notice that it is the option value multiplier $\frac{\beta}{\beta-1}$ that makes the distinction between the real options theory of investment and the neoclassical investment models. Since the option value multiplier $\frac{\beta}{\beta-1}$ mainly depends on the distribution of the stochastic variable of concern, it introduces the second moment of the stochastic variable (volatility) into the investment decision. On the right hand of (1), $(\rho - \mu_\pi)$ is the convenience yield.⁵ Therefore $\frac{\pi^*}{(\rho - \mu_\pi)}$ is the discounted critical value of profits. According to the neoclassical investment theory (equivalently the NPV rule) the project is undertaken if the expected discounted return from investment is not smaller than the investment cost. In the view of the real options theory of investment, the discounted expected return from investment must be larger than the investment outlay since $\frac{\beta}{\beta-1} > 1$, which implies that a higher expected return is required to compensate the possible loss due to uncertainty. As a consequence, the possible delay of investment makes fewer projects accepted as compared to the acceptable projects based on the NPV rule.

The definition of β (equation (2)) shows that the option value multiplier depends on the distribution of the stochastic variable of concern and the risk-adjusted discount rate of the firm. Therefore the problem of approximating the threshold value that triggers investment is in fact reduced to finding a way to model the expected distribution of the stochastic process. Under certain assumptions, the discount rate can be computed. Therefore all variables can be identified in equation (1) as long as we can find a way to model the future development of the profit process. In empirical analyses, we first construct β based on the information on the historical distribution of profits and the firm risk-adjusted discount rate (equation (2)). After that the option value multiplier $\frac{\beta}{\beta-1}$ is constructed. Next we set up the series of the threshold value of profits (π^*) based on equation (1) for each firm. It is specially interesting whether the difference between the actual value and the constructed threshold value of profits is able to explain firm investment. As we know that under the traditional investment rule (the NPV rule) this difference should not matter for firm investment.

3. Empirical Issues

3.1 Data

The data covers an unbalanced panel of 77 Dutch manufacturing firms during 1984-1997. These firms are all listed on the Amsterdam Stock Exchanges (AEX). The quoted firms are relatively big in size. Many of the sample firms can be considered to be monopolistic competitors on a world scale. Due to its historical roots, a majority of the Dutch listed firms are internationally oriented. The domestic firms in the sample are also relatively large as compared to the average firm size in the industry. As stated before in the standard real options model of investment, timing flexibility with respect to when to undertake investment mainly results from imperfect competition in product markets. Even with the delay of investment, the monopoly power of the firm can prevent other firms from entering the industry. In case that the entry happens, monopoly power can reduce the loss so that the benefit of waiting may be still attractive. The monopoly power enjoyed by the sample firms enables us to apply the data to the standard real options model of investment.

Table 1 gives descriptive statistics for some selected variables. It shows that profits fluctuate a lot. The value of the standard deviation of profits is about 3.5 times its mean value. The distribution of gross investment is dispersed, the standard deviation of investment is about 3.3 times its mean value.

Table 1 Descriptive Statistics
(unit: 10⁶ Guilders)

	Mean	Maximum	Minimum	Std.Dev.	Obs.
Gross Investment	271.76	9499	-1718	888.96	754
Capital Stock	1664.89	44723	1.06	5301.31	754
Profit	225.06	10936	-76	778.56	754
Sales Growth	0.1163	4.2612	-0.5214	0.2838	754
Payout Ratio	0.4331	11.522	0	49.6808	754
Depreciation Rate	0.1709	0.7702	0.0094	0.0788	754
Liquidity Ratio	0.4619	17.5769	0	1.3442	754
Option Multiple	11.0067	735.09	1.0554	50.62	754
Profit Threshold	317.76	16040.39	-14508.99	1454.23	754

(1) Data source: *Jaarboek van Nederlands Ondernemingen*

The data required to construct the threshold value of profits consist of the drift and the variance of the profit process, the risk-adjusted discount rate of the firm, and investment costs. Gross investment expenditures in each year are observable for each firm and are used to approximate the total direct investment outlay for that year. As far as the drift and the variance of profits are concerned, they should be forward-looking. When making irreversible investment decisions, the firm assigns subjective probabilities on the future development of profits, based on which the firm decides whether or not to postpone investment. By assuming that the objective distribution of profits exists, historical data

can be employed to model the firm's expectations on the future development of profits. Using historical data to construct the proxy for expected movement of stochastic variables is now a quite standard approach in empirical literature on the effect of uncertainty on investment (see for instance Ghosal and Loungani, 1996, 2000). Modeling the expected distribution of profits with a relatively short time series (14 years in our dataset) is not an easy task. However, we take into account all historical information about the movement of profits available to the firm. It is assumed that every year firms update their expectations on the future development of profits using the whole historical track of the profit process. More specifically, we calculate the drift of profits for the current year by taking the average of the growth rate of profits over the whole sample period in the past. For example, in 1987, the drift is approximated by the average of the growth rate using the 1985, 1986, and 1987 information;⁶ for the year 1988, the drift is computed based on the growth rates for the years 1985 to 1988 etc. In the similar way we calculate the variance of the profit process for the current year by taking the variance of the growth rate of profits over the whole past sample period.

The risk-adjusted discount rate needs more caution. In the standard real options model of investment (Dixit and Pindyck, 1994) it is often assumed that capital markets are sufficiently complete. With this assumption, stochastic changes in the value of the firm are spanned by existing assets in the economy, therefore the assumptions about risk preferences or discount rates are not relevant for making investment decisions. Without the spanning assumption (where the dynamic programming approach applies), all equity financing of investment is assumed. If the firm is assumed to be risk-neutral, the discount rate is just the risk-free interest rate. When risk-aversion is assumed, the convenience yield equals the dividend ratio paid by the underlying asset (for example, the investment project). Therefore the risk-adjusted discount rate of the firm is the sum of the average growth rate of the asset and the dividend ratio paid by the asset. Using the symbols of our model: $\rho = \mu_{\pi} + \delta$, where δ is the payout ratio of the firm. Therefore in the standard real options model of investment without the spanning assumption, a risk-averse firm discounts the investment opportunity partially due to the fact that the asset itself grows and partially because of the convenience yield by simply holding the dividend-paying asset.

Based on the above information, the option multiplier $\frac{\beta}{\beta-1}$ is constructed for each firm each year, the threshold value of profits is then constructed according to the structure of the model (equation (1)).⁷ The last two rows of Table 1 present the distributions of the constructed option multiplier and the threshold value of profits. As we can see, the mean value of the constructed option value multiplier is 11.01 with the standard deviation of 50.62. The value of the computed threshold for profits is on average larger than the mean value of the observed profits. These statistics suggest that there are indeed some firms whose actual values of profits are below the threshold values. These firms will wait until the actual value of profits hits its threshold level according to the real options theory of investment. In addition, we do observe that the option value multiplier varies a lot across firms, which indicates that the option value multiplier is firm-specific and the impact of the option value on investment depends on firm-specific characteristics. Not surprisingly, the threshold level of profits that triggers investment varies obviously across firms and over time.

3.2 Empirical Specification

The purpose of the paper is twofold. On the one hand we are interested in whether the sample firms intend to wait due to the consideration of the option values of investment opportunities. On the other hand we are interested in whether irreversibility or monopoly power plays a role in causing firms to postpone investment.

To test the waiting effect, a new variable ‘wait’ is defined as the difference between the observed value and the threshold value of profits. The reduced investment model we estimate reads:

$$\left(\frac{I}{K}\right)_{it} = f_i + f_t + \alpha_1 wait_{it} + \varepsilon_{it} \quad (3)$$

where f_i, f_t are firm and time effects. I_{it}, K_{it} represents gross investment and the capital stock of firm i at time t . α_1 is the parameter to be estimated. ε_{it} is the error term. We use a reduced form linear investment equation to check the waiting effect. In all estimations, the variable ‘wait’ is scaled by the capital stock to eliminate size effects. The

estimated coefficient of ‘wait’ is expected to be significant with a negative sign if the firm experiences waiting behavior. The intuition is that the interesting case for the subject matter of this study is when the actual profit is below the threshold value of profit. In this case the bigger the difference between the actual profit and its threshold, the severer the waiting behavior as predicted by the standard real options model of investment. This implies a lower investment ratio.

To test the association between the restriction of irreversibility and the delay of investment, we interact the variable ‘wait’ with proxies for irreversibility in estimating the reduced investment model:

$$\left(\frac{I}{K}\right)_{it} = f_i + f_t + \alpha_1 wait_{it} + \alpha_2 wait_{it} * proxy_{it} + \alpha_3 proxy_{it} + e_{it} \quad (4)$$

where α_2 represents the effect of irreversibility on investment which works via ‘wait’. *proxy* indicates the proxy for irreversibility. e_{it} is the error term. As to be discussed in the next section we will select two indicators for irreversibility, namely asset liquidity and the rate of depreciation of capital goods for each firm. In estimating (4), we isolate the own effect of ‘wait’ and the own effect of irreversibility by adding ‘wait’ and the proxy for irreversibility separately into the investment equation. Since the dependent variable is the ratio of gross investment to the capital stock, one could argue that the own effect of depreciation is already carried by firm fixed effects. Therefore there is no need to control the own effect of depreciation in estimating equation (4). Due to the above concern, in section 5 we report the results for both cases when the own effect of depreciation is controlled and when it is not controlled. Once again in all estimations, ‘wait’ is scaled by the capital stock. Since both proxies for irreversibility are ratios, they are not scaled by the capital stock. In estimating equation (4) special attention is paid to whether the estimated coefficient of the interactive term α_2 is significant.

3.3 Estimation Method

The profit threshold is a constructed proxy for the investment trigger that is by nature unobservable. This implies that the variable ‘wait’ suffers from measurement errors. In addition, ‘wait’ is obviously an endogenous variable, it correlates with the error term in the investment equation on the one hand and with firm fixed effects on the other. Under these circumstances we choose the Generalized Method of Moments (GMM) to estimate the effect of ‘wait’ on investment.

In principle we can run the GMM estimation in first differences by assuming no serial correlation of the error term. However, first difference GMM estimators may suffer from weak instruments problem in some cases. Blundell and Bond (1998) prove that for a dynamic panel data model, the standard GMM estimator is biased either when the lagged dependent variable is highly correlated with the current dependent variable or when heteroskedasticity is high across cross-section units. For firm-level investment analyses, we expect high heteroskedasticity across firms due to the fact that there are so many endogenous factors that interact with each other in affecting the response of firm investment to uncertainty. Not all relevant variables are reflected by the variable ‘wait’. These missing effects are expected to be carried by the error term of the investment model. As the consequence we adopt the system GMM estimation procedure proposed by Blundell and Bond (1998), in which moment conditions for equations in first differences are combined with moment conditions for equations in levels to compute the optimal weighting matrix that provides consistent system GMM estimators.

4. Proxies for irreversibility

As mentioned earlier, one of the key assumptions of the real options theory of investment is irreversibility. However, the impact of irreversibility on investment is debated (see the introduction). Therefore it is natural to pick up some indicators that may reveal some information on the restriction of irreversibility faced by the firm in order to test whether irreversibility alone is an important factor that forces firms to wait to invest.

The wedge between purchasing and reselling prices of capital goods may result from either the fact that capital goods are firm- or industry-specific or from the notion that secondary markets for capital goods are missing or that those markets are not efficient (Pindyck, 1991). It may also arise due to the asymmetric information (lemons) problem. In the literature some empirical proxies of irreversibility are proposed. Guiso and Parigi

(1999) use two different indicators of irreversibility: (i) the degree of access to secondary markets for installed capital goods; (ii) the degree of the cyclical volatility of the firm's industry. The intuition behind the second proxy is that the more cyclical the industry is, the more illiquid the firm's capital might be. Pattillo (1998) uses as a proxy for irreversibility the ratio of real sales to replacement value of the capital stock. Bell and Campa (1997) split investment projects (on chemical products) by the type of investment: greenfield investment versus capacity expansions. Greenfield plants involve a greater amount of sunk costs than investment in capacity expansions. Therefore the degree of irreversibility in greenfield plants is higher than that in capacity expansion. In Pindyck (1986), the proxy for irreversibility is the physical property embedded in aggregate capital goods. The investment in structures is more irreversible as compared to the investment in equipment. Unfortunately, the information on purchasing and reselling prices of capital goods and that on the access to the secondary capital goods markets are not available for our sample. The data restricts us to choose some indirect variables that are expected to reveal some information on the restriction of irreversibility faced by the firm.

First we use asset liquidity as the proxy for the restriction of irreversibility. In the corporate finance literature, the transaction costs model predicts that if a large fraction of the assets owned by the firm is liquid, the firm owns more firm-specific assets (Shleifer and Vishny, 1993), implying a severer restriction of irreversibility. The intuition is that if the firm owns more non-specific assets, it is easier for the firm to resell assets in the secondary capital goods markets to raise funds with lower transaction costs, then a higher level of liquid assets is not necessarily held by the firm because holding liquid assets is also costly. One of the reasons of holding liquid assets is due to its buffer effect as pointed out by Opler, Pinkowitz, Stulz and Williamson (1999). Since the firm saves transaction costs in raising funds by holding liquid assets, the firm can avoid going to the secondary capital goods markets very often to liquidate its fixed assets to make payments. Therefore holding a higher level of liquid assets suggests that the firm is likely to have more difficulties in reselling capital goods and then is expected to face more restrictions of irreversibility. Hence the liquidity ratio may reveal some information on the restriction of irreversibility. We calculate the liquidity ratio for each firm using the value of liquid assets to the value of the capital stock. We expect that the higher the liquidity ratio, the severer the restriction of irreversibility and the larger the waiting effect of investment. In other words, the interaction between asset liquidity and 'wait' is expected to be positive.

The second proxy for irreversibility is the speed of depreciation of capital goods. Depreciation includes physical deterioration and the efficiency decline of capital goods with the passage of time. The speed of economic depreciation of capital goods reveals the speed of technology development and the changes in economic conditions. It is related to the shadow value of existing capital goods. If we assume that there are secondary markets for capital goods, the reselling prices of capital goods should be set based on the book or the market value of assets, while depreciation provides the information on how much value has been deducted from the book value of assets. Therefore the higher the rate of depreciation of capital goods, the quicker the recovery of the sunk cost of investment and the less concern for the possible loss resulted from reselling capital goods in secondary markets. Therefore we expect that the interaction between the depreciation policy and 'wait', if any, is negative. Chirinko (1996) claims that accelerating depreciation may wash off the constraints created by irreversibility. Pindyck (1988) also mentions that if capital becomes obsolete rapidly, the opportunity cost of investing will be small. Ghosal (1995) in a study of the impact of price uncertainty on industry output concentration uses depreciation to proxy for sunk costs, claiming that speedy depreciation lowers sunk costs.

5. Empirical Results

5.1 Main Tests

The system GMM estimation is conducted by using the package of DPD98 for Gauss (Arellano and Bond, 1998). The instruments are chosen based on the principle that the information on the right-hand side variables is used as much as possible until the valid lowest value of Sargan statistic is obtained. Time dummies from 1984 to 1997 are added in all estimations and therefore used as additional instruments. The results of estimating equation (3) are reported in column (1) of Table 2. We observe that the sample firms are on average concerned with the option value of investment opportunities in making investment decisions. The estimated coefficient of 'wait' has a negative sign and is highly significant. The test statistic for the absence of first-order serial correlation in the first-differenced residuals (m_1) is highly significant with a negative sign, indicating that the disturbances ε_{it} are not serially correlated. The test of second order serial correlation (m_2) is not significant, confirming no serial correlation in the error term. The Sargan test

statistic supports the validity of the instruments used in the estimation. The coefficient test (Wald) rejects at the 5% level the null hypothesis that there is no waiting effect.

Table 2 The effect of waiting on investment: main tests

	1	2	3	4
Wait	-0.0161 <2.3832>	-0.0239 <-2.2664>	-0.07589 <-1.9461>	-0.0769 <-2.1294>
Wait*liquidity		8.00E-03 <0.7593>		
Liquidity		-0.0099 <-0.4351>		
Wait*depreciation			0.3297 <1.8674>	0.3417 <1.9941>
Depreciation			0.5486 <1.5088>	
m ₁	-2.226	-2.4	-2.654	-2.856
m ₂	-0.522	-0.595	-0.774	-0.546
Wald test	H ₀ :α ₁ =0	H ₀ :α ₁ =0	H ₀ :α ₁ =0	H ₀ :α ₁ =0
Chi-square	5.679	5.137 H ₀ :α ₂ =0	3.878 H ₀ :α ₂ =0	4.534 H ₀ :α ₂ =0
		0.577	3.487	3.977
Sargan(k)	61.483(53)	66.114(150)	66.841(150)	65.946(100)
Instruments	wait _{t-2...}	wait _{t-2...t-8} wait*liquid _{t-2...t-8} liquidity _{t-2...t-8}	wait _{t-2...t-8} wait*dep _{t-2...t-8} depreciation _{t-2...t-8}	wait _{t-2...t-8} wait*dep _{t-2...t-8}

Notes:

(1) Data source: *Jaarboek van Nederlands Ondernemingen*

(2) The one-step estimates with robust test statistics are reported

(3) Heteroskedasticity consistent asymptotic t-statistics are in parentheses

(4) m₁: test of first-order serial correlation

- m_2 : test of second-order serial correlation
- (5) Sargan(k): test of the overidentifying restrictions, asymptotically distributed as Chi-square (k) under the null
- (6) Instrument variables are the observations dated at (t-2) and earlier of the right hand side variables
- (7) Explanations of variables:
- I/K : the investment to capital ratio
 - wait* : the difference between observed and threshold values of profits
 - proxy* : the proxy for irreversibility
 - liquidity: the liquid ratio of assets
 - depreciation: the rate of depreciation of capital goods

The second column of Table 2 displays the results of estimating equation (4) when the proxy for irreversibility is asset liquidity. The estimated coefficient of ‘wait’ remains significant with a negative sign, indicating that the difference between the realizations of profits and the threshold values of profits indeed depresses investment. The Wald coefficient test rejects the null at the 5% level. The interesting result concerns the effect of irreversibility on investment that is conducted via ‘wait’. As we can see that the estimated coefficient of the interactive term is positive as we are expecting but it is not significant, indicating that there is no important association between the delay of investment and asset liquidity based on our dataset. Tests of the absence of first-order and second-order serial correlation in the first difference residuals are all satisfactory. The Sargan statistic also supports the validity of the instruments.

Column (3) and (4) of Table 2 show the system GMM estimation results for equation (4) when the rate of depreciation of capital goods is used as the proxy for irreversibility. In the estimation of column (3) the own effect of depreciation is controlled. In column (4) we do not isolate the own effect of depreciation due to the concern that it is carried by firm fixed effects. As we see that the results are quite consistent across the two cases. The estimated waiting effect remains significantly negative. The estimated coefficient of the interactive term is significant but it has a wrong (positive) sign, indicating that the speed of depreciation affects investment but not through the restriction of irreversibility.

To summarize the evidence we found so far, the sample firms are on average concerned with the opportunity costs of excising investment options. Using asset liquidity and the speed of depreciation as indirect proxies for irreversibility to check the association between the delay of investment and the restriction of irreversibility, we find that neither asset liquidity nor depreciation policies are important factors that cause firms to wait to invest.

5.2 Robustness checks

To check the robustness of the system GMM estimates obtained from estimating the reduced investment equation, we further control the growth opportunity of the firm in the investment equation and repeat the estimations. The growth opportunity of the firm is approximated by the growth rate of sales. The results are reported in Table 3. As shown by the first row of Table 3, the estimated coefficient of the growth rate of sales is significant with the positive sign in three out of four cases, basically confirming the accelerator effect. The estimated waiting effect remains significantly negative in all cases. All coefficient test statistics are satisfactory. The estimated interaction between ‘wait’ and the rate of depreciation is significant but again with the positive sign. This result implies that the higher the rate of depreciation, the severer the waiting effect, which again suggests that the mechanism through which the depreciation policy affects investment is not the restriction of irreversibility. On the other hand, as we found in Table 2 assets liquidity does not interact with ‘wait’.

The results reported in Table 2 and Table 3 are based on the profit threshold that is constructed by approximating the expected distribution of profits using the whole historical movement of profits. Since this is only one of the ways of modeling the future development of a stochastic process using historical data, the results might be sensitive to the choice of the modeling method. As another robustness check, we approximate the expected distribution of profits by using a window of fixed length (5-year historical data). An alternative profit threshold series is constructed for each firm. We calculate the 5-year moving average of the growth rate of profits and dated it in the fifth year as the drift of the profit process for that year. We use the 5-year moving variance of the growth rate of profit as the variance of the profit process for the fifth year. The same risk-adjusted discount rate of the firm is used in constructing the alternative threshold value of profits. Using the alternative threshold to redefine the variable ‘wait’, we repeat all estimations of Table 2 and Table 3. The results are highly consistent with what we obtained in both Table 2 and Table 3.⁸

Table 3 The effect of waiting on investment: robustness tests

	1	2	3	4
S ^g	0.1983 <1.8298>	0.1522 <1.7341>	0.1467 <1.5699>	0.1554 <1.9874>
Wait	-0.0181 <-2.3084>	-0.0209 <-2.5105>	-0.0674 <-2.0651>	-0.0776 <-2.0365>
Wait*liquidity		7.10E-03 <0.7653>		
Liquidity		-0.0029 <-0.1539>		
Wait*depreciation			0.2958 <1.9838>	0.3466 <1.9176>
Depreciation			0.7128 <1.9278>	
m ₁	-1.987	-2.085	-2.187	-2.516
m ₂	-1.076	-1.011	-1.215	-1.022
Wald test	H ₀ :α ₁ =0	H ₀ :α ₁ =0	H ₀ :α ₁ =0	H ₀ :α ₁ =0
Chi-square	5.329	6.302 H ₀ :α ₂ =0	4.265 H ₀ :α ₂ =0	4.147 H ₀ :α ₂ =0
		0.586	3.936	3.677
Sargan(k)	63.839(106)	64.472(128)	65.917(128)	58.661(150)
Instruments	S ^g _{t-2...} wait _{t-2...}	S ^g _{t-2...t-4} wait _{t-2...t-4} wait*liquid _{t-2...t-4} liquidity _{t-2...t-4}	S ^g _{t-2...t-4} wait _{t-2...t-4} wait*dep _{t-2...t-4} depreciation _{t-2...t-4}	S ^g _{t-2...t-8} wait _{t-2...t-8} wait*dep _{t-2...t-8}

Notes: see notes for Table 2

5.3 Additional Explanations

The system GMM estimates in general do not support the relevance of our proxies of irreversibility to the delay of firm investment. The irrelevance of irreversibility to the delay of investment might be explained by the lack of appropriateness of our proxy variables or some special characteristics of the sample firms. First of all, many of the sample firms are multinational corporations. They operate on international markets and their assets are relatively diversified with respect to both operating locations and types of assets. Lang and Stulz (1994) document that a firm becomes more diversified as its number of segments increases. Since diversified firms are more likely than specialized firms to have substantial assets that can be easily sold due to the fact that they can sell non-core segments, diversification obviously reduces the restriction of irreversibility (also see Opler, Pinkowitz, Stulz and Williamson, 1999). Secondly, the sample firms are all large listed firms in the Netherlands, they have few problems in accessing to external capital markets and the asymmetric information (lemons) problem is less severe for these firms. Therefore transaction costs relating to reselling capital goods are relatively low. Finally, capital markets are well developed in the Netherlands, which probably mitigates the restriction of irreversibility on firm investment in general. If irreversibility is not such an effective factor that drives firms to wait to invest, then the existence of the investment waiting behavior suggests that the sample firms enjoy timing flexibility in arranging their investment. It is therefore more likely that imperfect competition is responsible for the higher investment hurdles confronted by the sample firms. Other studies indeed find evidence of monopolistic competition of Dutch firms (see Van Ees, Garretsen, De Haan, and Sterken, 1998).

To further explain the waiting effect, we need the data on market power for the sample firms, which is not available in the data set we used in the previous estimations. To obtain an indicator of market power, we use another data set, namely *AMADEUS*. The profit margin is chosen as the indicator of market power. In *AMADEUS*, the profit margin is constructed as the ratio of operating profit before taxation to operating revenue (turnover). Among the original 77 sample firms, there are 16 firms that either have no data on the profit margin or the data is not continuous over at least 5 years. So that we are left with 61 sample firms in this set of estimations. Since *AMADEUS* only reports 5-year continuous observations, we select the data of the profit margin over the period of 1994-1999. Some of the sample firms have data on the profit margin from 1994-1998. Others

have the observations from 1995-1999. We calculate the average value of the profit margin for the 61 sample firms over continuous 5-year observations. Then we define a dummy variable $pm_i = 1$ if firm i has the average value of the profit margin which is above the median of the whole (61) sample firms. $pm_i = 0$ if firm i 's average profit margin is below the sample median. The sample median is 5.2577.⁹ The following investment equation is then estimated by using the system GMM procedure:

$$\left(\frac{I}{K}\right)_{it} = f_i + f_t + \alpha_4 wait_{it} * pm + \alpha_5 wait_{it} * (1 - pm) + v_{it} \quad (5)$$

Where the coefficient of α_4 captures the effect of 'wait' on the investment decision of the firms that have relatively higher market power, while α_5 captures the effect of 'wait' on the investment decisions of the firms that have lower market power. v is the error term. If it is market power (timing flexibility) that explains the waiting behavior of the sample firms, then we would expect α_4 and α_5 to be different. The estimated value of α_4 should be larger in the absolute value than that of α_5 . The higher the market power the more timing flexibility of the firm. The firm is more likely to wait to invest if it has greater timing flexibility with respect to when to undertake investment. Therefore a lower investment ratio is expected. All other variables in (5) are defined in the same way as in the previous estimations of this paper. The estimated values of α_4 and α_5 are expected to be negative as before. To be consistent with the former estimation of Table 3, we also estimate equation (6), in which the growth opportunity of the firm is controlled. Here the growth of sales is redefined by using the dummy variable pm .

$$\begin{aligned} \left(\frac{I}{K}\right)_{it} = & f_i + f_t + \alpha_4 wait_{it} * pm + \alpha_5 wait_{it} * (1 - pm) + \\ & + \alpha_6 S_{it}^g * pm + \alpha_7 S_{it}^g * (1 - pm) + \zeta_{it} \end{aligned} \quad (6)$$

where S_{it}^g indicates the growth rate of sales for firm i at time t . ζ is the error term. α_6 and α_7 are parameters. Table 4 displays the system GMM results of the impact of market power on the waiting effect.

Table 4 The impact of market power on the waiting effect

	1	2	3
S^g*pm			0.0549 <0.7069>
$S^g*(1-pm)$			0.5644 <2.0021>
Wait	-0.0186 <-2.2368>		
Wait*pm		-0.0307 <-3.7184>	-0.0305 <-3.0273>
Wait*(1-pm)		-0.0229 <-1.7576>	-0.0193 <-1.8237>
m_1	-2.072	-2.115	-1.836
m_2	-0.626	-0.727	-1.221
Wald test	$H_0:\alpha_1=0$	$H_0:\alpha_4=0$	$H_0:\alpha_4=0$
Chi-square	5.003	13.826 $H_0:\alpha_5=0$ 3.089	9.165 $H_0:\alpha_5=0$ 3.326
Sargan(k)	52.352(50)	48.345(100)	48.567(128)
Instruments	$wait_{t-2...t-8}$	(t-2)...(t-8) all regressors	(t-2)...(t-4) all regressors

Notes: see notes for Table 2 pm :dummy variable indicating profit margin

Using the 61 firms, we re-estimate equation (3) to check the robustness of the results in the first column of Table 2. The first column of Table 4 shows that the estimated waiting effect is closely consistent with the former results. Column (2) of Table 4 reports the results for estimating (5) and column (3) of Table 4 shows the results of estimating (6). As shown by column (2) and (3) of Table 4, the estimated waiting effect is more severer for the firms that have relatively higher profit margin, while the firms that have lower market power experience modest waiting behavior. The Wald test statistic shows that the estimated coefficient of 'wait' for the firms that have lower profit margin is significantly different from zero only at the 10% level in both column (2) and (3) of Table 4, while the Wald test statistics is highly significant (at 0.1% and 1% levels, respectively) for the firms that have higher profit margin. Moreover, the estimated waiting effect for high market power firms is much stronger as compared with the results shown by column (1) of Table 2 and column (1) of Table 3. These results indicate that market power indeed enforces the waiting effect. These results lend a strong support to the notion that imperfect competition or market power explains why the sample firms on average are confronted with higher investment hurdles. The evidence shows that the market power enjoyed by the sample firms provides them with timing flexibility with respect to when to undertake their investment.

6. Conclusions

The paper tests a standard real options model of investment using an unbalanced panel of 77 listed Dutch manufacturing firms during 1984-1997. The application of firm-level data (rather than at project-or plant-level) to the real options model of investment is scant in the literature. This study attempts to make a contribution to this field.

We assume that the managers of the firm act in accordance with the real options theory of investment. By first modeling the future development of profits based on the historical movement of the profit process, we are able to construct the option value multiplier under the assumption of the risk-averse attitude of the firm. After that the profit threshold value is approximated based on the structure of a standard real options model of investment (Dixit and Pindyck, 1994). Special attention is paid to whether the difference between the actual value and the threshold value of profits affects firm investment.

Moreover, we check the role played by irreversibility in causing firms to wait to invest by employing two indirect proxies for the restriction of irreversibility.

The system GMM estimates support the basic prediction of the real options theory of investment. The sample firms are found to care about the opportunity costs of exercising investment options. The difference between the observed profits and the threshold values of profits (wait) is consistently found to depress firm investment, implying that the sample firms on average intend to wait until the actual value of profits hits its threshold level. Nevertheless, there is no convincing evidence that shows that asset liquidity and depreciation policies can explain the waiting behavior of the sample firms, suggesting that irreversibility is probably not an important concern for the sample firms to postpone investment. This may be explained by the fact that we do not have access to the information directly related to the secondary markets for capital goods, which makes the two indirect proxies for irreversibility less informative. On the other hand if these proxies indeed reveal some information on the restriction of irreversibility, the result lends a support to the notion that irreversibility alone does not always depress investment. Some characteristics of the sample firms might be important in explaining the irrelevance of the restriction of irreversibility. Financial markets are well developed in the Dutch economy, which mitigates the restriction of irreversibility on firm investment in general. In addition, the sample firms are all large listed firms in the Netherlands. The asymmetric information (lemons) problem is less severe for them and they have easier accesses to external capital markets. These factors are expected to narrow the wedge between purchasing and reselling prices of capital goods for the sample firms. Moreover, many of the sample firms are multinational corporations. They operate on international markets and the assets owned by these firms are relatively diversified with respect to both operating locations and types of assets. Diversification is also expected to reduce the restriction of irreversibility. If irreversibility is not an effective factor that drives firms to wait, then imperfect competition might be responsible for higher investment hurdles confronted by the sample firms. Further evidence indeed shows that higher market power is associated with severer waiting effects, indicating that it is imperfect competition or market power that provides the sample firms with timing flexibility with respect to when to undertake investment.

Appendix A: The derivation of the investment model

The investment model we derive here is based on the standard real option model of investment (Dixit and Pindyck, 1994). A risk-averse firm decides whether to start a new capital investment project in the current year. Suppose that the value of the firm is the expected value of the profit stream that is generated by the new capital. The profit process is stochastic due to uncertain operating conditions, which is assumed to follow a geometric Brownian motion:

$$\frac{d\pi}{\pi} = \mu_{\pi} dt + \sigma_{\pi} dz \quad (\text{A1})$$

Where π is the profit generated by the investment. dz is the incremental of a standard Wiener process, with $E[dz] = 0$, and $E[(dz)^2] = dt$. μ_{π} is the drift and σ_{π} is the standard deviation of profit. The value of the firm fluctuates with the changes in profits. Suppose that the firm has the option to postpone the current investment. In this case the investment outlay is saved. If the firm decides to invest right now, the value of the firm will be the discounted present value of future profits generated from the investment. We denote the expected value of the firm if it invests now as $V_{now}(\pi)$, then:

$$V_{now}(\pi) = \int_0^{\infty} E(\pi_t) e^{-\rho t} dt \quad (\text{A2})$$

Where π_t is the profit of the firm at time t . E is the expectation operator. ρ is the risk-adjusted discount rate of the firm. We assume $\rho > \mu_{\pi}$ to be consistent with the standard real option model of investment.

Solving equation (A2) and noticing that $E(\pi) = \pi e^{\mu_{\pi} t}$ because of the assumption of equation (A1), we have:

$$V_{now}(\pi) = \frac{\pi}{\rho - \mu_\pi} \quad (A3)$$

This is the discounted present value of the firm if it starts to invest in the current year. However, if the firm decides to postpone the investment, the present value of the firm is the value of the investment opportunity. If we denote the present value of the firm in case of waiting as $V_{wait}(\pi)$, it needs to satisfy the Bellman equation:

$$\rho V_{wait}(\pi) dt = E[dV_{wait}(\pi)] \quad (A4)$$

As widely documented in the literature (MacDonald and Siegel, 1986; Dixit and Pindyck, 1994), by Ito's Lemma and using (A1), we can solve for $E[dV_{wait}(\pi)]$ and (A4) becomes:

$$\frac{1}{2} \sigma_\pi^2 \pi^2 V_{wait}''(\pi) + \mu_\pi \pi V_{wait}'(\pi) - \rho V_{wait}(\pi) = 0 \quad (A5)$$

Where $V_{wait}'(\pi), V_{wait}''(\pi)$ are the first and the second order derivatives of the value of the firm with respect to profits, respectively. The solution to the differential equation (A5) must satisfy the boundary condition:

$$\lim_{\pi \rightarrow 0} V_{wait}(\pi) = 0 \quad (A6)$$

As widely proved in the literature, the solution is:

$$V_{wait}(\pi) = A\pi^\beta \quad (A7)$$

Where A is a constant and β is the positive root of the characteristic equation of (A5):

$$\beta = \frac{1}{2} - \frac{\mu_\pi}{\sigma_\pi^2} + \left[\left(\frac{\mu_\pi}{\sigma_\pi^2} - \frac{1}{2} \right)^2 + \frac{2\rho}{\sigma_\pi^2} \right]^{\frac{1}{2}} \quad (A8)$$

To solve the threshold level of profits, both the value matching and smooth pasting conditions have to be satisfied:

$$V_{wait}(\pi^*) = V_{now}(\pi^*) - IC \quad (A9)$$

and

$$V'_{wait}(\pi^*) = V'_{now}(\pi^*) \quad (A10)$$

Where IC represents the investment cost. The value matching condition (A9) states that at optimal the firm is indifferent between investing right now and delaying the investment. The smooth pasting condition (A10) guarantees that the value function of the firm is continuous at the threshold value of profit (π^*) if π^* maximizes the value of the firm. We will measure the cost of investment by the observable gross fixed investment undertaken by the firm at time t . By the value matching condition,

$$A\pi^{*\beta} = \frac{\pi^*}{\rho - \mu_\pi} - IC_t \quad (A11)$$

By the smooth pasting condition,

$$A\beta\pi^{*\beta-1} = \frac{1}{\rho - \mu_\pi} \tag{A12}$$

Solving equation (A11) and (A12) simultaneously, we have:

$$\pi^* = \frac{\beta}{\beta-1}(\rho - \mu_\pi)IC_t \tag{A13}$$

Equation (A13) is the threshold level of profits. $\frac{\beta}{\beta-1}$ is the so called ‘option value multiplier’.

Appendix B: Data Description

(1) The main data used in this paper is taken from the publication of *Jaarboek van Nederlandse Ondernemingen*. The 77 manufacturing firms in the data set are listed on the Amsterdam stock exchange (AEX) over the period of 1984–1997 in the Dutch economy. In this data set:

Gross Investment = capital goods investment, which is the sum of the changes in the capital stock and the depreciation of the capital stock.

Capital Stock = the book value of the capital stock.

Profit = operating profits after tax and before interest payments.

Payout Ratio = the ratio of dividend per share to net profit per share.

Depreciation Rate = the ratio of the depreciation of the capital stock to the beginning-of-year capital stock.

Liquid ratio = the ratio of liquid assets to the capital stock.

Sales = the product of the output price and the amount of product sold.

(2) The data on profit margin is downloaded from *AMEDEUS* online information service. Among the 77 Dutch listed firms in the data set (1), there are 61 firms that have continuous 5-year observations of profit margin over the period of 1994-1995 in *AMEDEUS*. The construction of profit margin is:

profit margin (%) = (operating profit before taxation/operating revenue(turnover)) * 100

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Endnotes

¹ Irreversibility implies that once capital goods are purchased the reselling prices are lower than their purchasing prices. A broader view of irreversibility means that revising investment decisions is always costly.

² Caballerro (1991) deals with the case of product markets, in which the source of uncertainty is from product market conditions, such as the output price, and the demand faced by the firm. Under these circumstances, the assumptions of imperfect competition and/or decreasing returns to scale are important since they ensure that the value function of the firm is concave in capital.

³ See Dixit and Pindyck (1994), Chapter 5.

⁴ If this assumption does not hold, the firm will never invest since waiting is always better than investing.

⁵ For a storable commodity, convenience yield represents the net marginal convenience yield from storage. It is the flow of benefits (less storage costs) that the marginal stored unit provides. See Dixit and Pindyck (1994), Chapter 6, pp179.

⁶ The profit series starts from 1984 in our dataset, so the series of the growth rate of profit starts from 1985.

⁷ We have to drop some observations that have the value of β less than or equal one to be consistent with the theory. The total firm-year observation left is 754 in final estimations.

⁸ To save space we do not formally report this set of estimation results. They are available on request.

⁹ The mean value of average profit margin of these 61 firms is 5.9179. The median is 5.2577. Standard deviation is 4.3851, Skewness is -0.4032 and Kurtosis is 4.6238.