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AN EMPIRICAL INVESTIGATION OF THE IMPLICATIONS OF THE REAL OPTIONS APPROACH FOR INVESTMENT IN THAILAND

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Abstract. The real options theory of investment argues that uncertainty has a negative impact on irreversible investment and that the negative impact is more significant with an increasing level of irreversibility. This paper focuses on examining the implications of the real options approach to irreversible investment under uncertainty. Using the implication of the real options approach we investigate the following hypotheses: (i) uncertainty has a negative impact on positive fixed investment; (ii) irreversibility strengthens the negative impact of uncertainty on investment. We found evidence confirming the validity of the real options analysis to irreversible investment problems in the emerging market of Thailand.

Keywords: *Investment, Uncertainty, Real Options, Panel Data.*

1. Introduction

Investment irreversibility, uncertainty, and timing flexibility give rise to the option-like feature of investment opportunities. A call option offers the call holder the right to buy, while a put option gives the put holder the right to sell. Analogous to financial options, an investment opportunity is an American call option with a perpetual expiry date. The investor has the right to pay the exercise price (which, in this case, is the cost of investment and is irreversible) and receive an asset in return (which is the realised value of the investment) at any time on or before the expiry date, which is perpetual (McDonald and Siegel, 1985).

Capital budgeting has largely been guided by the Net Present Value (NPV) rule, based on the neoclassical theory of investment. The real options approach differs from the NPV rule in the sense that it takes into account the irreversibility of capital, uncertainty and the timing flexibility. The two approaches are essentially distinct from each other by their assumptions and methodologies rather than the results obtained. The real options approach assumes the stochastic variation in the value of investment while the NPV approach assumes the smooth functional form of project values and uses the simple discounted cash flows for inter-temporal analysis. Once the value of the waiting option is incorporated as part of the investment expenditure, the basic results given by the option approach and the traditional net present value rule are essentially equivalent, thus the old rule can still be applied (Pindyck, 1988).

The option value of waiting to invest creates a wedge between the required expected return on investment and the cost of investment, which characterizes firms' investment behaviours featuring hysteresis. Hysteresis means that firms will not follow the standard NPV investment rule to make investments immediately after the expected returns on investments reached a level high enough to cover investment costs. Instead, they will wait until the expected returns reach the level that is high enough to cover both the cost of investment and the foregone waiting option value. The mentioned wedge increases in line with the increase of uncertainty level. Under high uncertain environment, this wedge can be considerable large and waiting can be widely observed. Thus, uncertainty can be a powerful force of investment deterrence. Given a level of uncertainty, if irreversibility is not absolute but partial, an increase in the degree of partial irreversibility will also raise the wedge and deter investment (McDonald and Siegel, 1986).

The real options approach to investment under uncertainty gives us important insights into firms' investment behaviour. First, the lost option value as firms decide to exercise their waiting option to invest is an opportunity cost that must be included as part of the cost of investment. Thus, the traditional NPV rule must be modified to include this opportunity cost. Second, this opportunity cost is sensitive to uncertainty or changing economic conditions over the future value of the investment. Hence uncertainty has an important impact on investment spending and sometimes this impact is even more important than interest rates. Third, firms would make (or abandon) an investment only when the present value of expected return of the project reaches a "hurdle" level, which is sufficiently higher (or lower) than the cost of capital. The hurdle level is an increasing function of uncertainty (Dixit, 1992).

Because of the difficulties in obtaining firm-level data, empirical studies on investment have used aggregate data and concentrated on the combined net effect of the uncertainty on investment. Empirical investigations on investment under uncertainty using firm-level data are therefore important for bridging the gap of deficiencies and inadequacy with regards to both theoretical and empirical aspects of the existing literature on the real options approach. This research attempts to make such investigation in verifying the empirical validity of the real options approach for the emerging market of Thailand.

2. The Basic Real Options Model of Investment

We examine an investment problem, introduced by McDonald and Siegel (1986) in their pioneer article, and Dixit and Pindyck (1994) in their seminal work, where firms have some investment opportunities, which can either be invested now or deferred until the next period for better information. The problem examined is an *optimal stopping problem* with the choice of exercising the option to invest and incurring the opportunity cost of foregoing the option to wait another period, versus waiting another period with the expectation that the value of the option will increase.

Suppose the value of a project, V, evolves according to a stochastic diffusion process called the geometric Brownian motion of the form:

$$dV = (\rho-\delta)Vdt + \sigma Vdz \qquad (1)$$

Where ρ is the instantaneous actual expected return on the project, δ denotes the proportional cash flow pay-out (dividend) on the operating project[1], σ is the instantaneous standard

[1] See McDonald and Siegel (1984, 1985). δ may also represent the net convenience yield in the case of commodities. We assume $\mu = \rho - \delta$ is the growth rate parameter of the project with $\mu < \rho$ so that $\delta = \rho - \mu > 0$ and the optimal problem is deterministic. Otherwise, waiting forever is always a better strategy.

deviation of the project value, and dz is the increment of the standard Wiener process. Our purpose is to find out the optimal expected value, V^*, at which firms should decide to invest and maximise its expected net payoff value of the investment opportunity, $F(V)$, over the time horizon, T

$$F(V) = max\ E[(V_T - I)\ e^{-\rho T}] \qquad (2)$$

where $E[\cdot]$ denotes expected value, and ρ, as defined above, can be used as the appropriate discount rate. Using Bellman Optimisation Principle[2] and by backwardation, we can deduce that for a policy to be optimal, all of its sub-problems for each time increment dt should be optimal. Hence:

$$F(V,t) = \max \{V - I,\ e^{-\rho dt}\ E[F(V+dV,\ t+dt)|V]\} \qquad (3)$$

By L'Hôpital's rule, we have:[3]

$$F(V,t) = \max \{V - I,\ (1+\rho dt)^{-1}E[F(V+dV,\ t+dt)|V]\} \qquad (4)$$

In the language of dynamic programming, the maximum on the right-hand side of this equation will be achieved by some range of V in the continuation region (waiting) and some range of V in the termination region (investing)[4]. In the continuation region $F(V,t) = (1+\rho dt)^{-1}E[F(V+dV, t+dt)|V]$, in the termination region $F(V,t) = V - I$. There is a cut-off point V^*, where $V^* - I = (1+\rho dt)^{-1}E[F(V+dV, t+dt)|V]$. To the left of V^*, it is optimal to wait, and to the right of V^*, it is optimal to invest. V^* is the optimal point, at which firms should go and invest. Hence, at the optimal cut-off point:

$$F(V,t) = (1+\rho dt)^{-1}E[F(V+dV,\ t+dt)|V] \qquad (5)$$

Multiply both sides by $(1+\rho dt)$:

$$(1+\rho dt)F(V,t) = E[F(V+dV,\ t+dt)|V] \qquad (6)$$

And rearrange the equation to get the reduced form of the Bellman equation:

$$\rho F dt = E[F(V+dV,\ t+dt)|V] - F(V,t) = E(dF) \qquad (7)$$

Using Ito's Lemma to expand dF and substituting equation (1) for dV gives

$$dF = F_V dV + \frac{1}{2}F_{VV}(dV)^2 \qquad (8)$$

hence

$$E(dF) = (\rho - \delta)F_V dt + \frac{1}{2}\sigma^2 V^2 F_{VV} dt \qquad (9)$$

This equation and the Bellman equation (7) above give

$$\rho F dt = (\rho - \delta)F_V dt + \frac{1}{2}\sigma^2 V^2 F_{VV} dt \qquad (10)$$

Dividing both sides of this equation by dt and rearranging terms results

$$\frac{1}{2}\sigma^2 V^2 F_{VV} + (\rho - \delta)VF_V - \rho F = 0 \qquad (11)$$

To solve this equation, we need to derive some other boundary conditions that $F(V)$ must satisfy. The geometric Brownian motion ensures that if V goes to zero, then it will stay at zero forever, then, in the language of the stochastic process, the following *lower boundary condition* must be

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[2] The Bellman Optimisation Principle states that regardless of the initial action, an optimal policy should satisfy the conditions that any sub-problem, starting at the state that results from the initial actions, should constitute an optimal policy.

[3] By L'Hôpital's rule, $\lim_{dt \to 0} \frac{e^{\rho dt} - 1}{\rho dt} = \lim_{dt \to 0} \frac{\rho e^{\rho dt}}{\rho} = 1 \Leftrightarrow e^{\rho dt} \underset{dt \to 0}{\Rightarrow} (1 + \rho dt)$, where dt is set to equal x, and the derivatives of both numerator and denominator with respect to x is taken for the original limit function.

[4] In *Figure 1* the continuation region is to the left of V^*, and the termination region is to the right of V^*. V^* is the optimal value at which stop waiting and invest is optimal.

satisfied

$$F(0) = 0 \qquad (12)$$

At the optimal stopping value, V^*, at which it is optimal to invest, firms cease to hold the option to invest and undertake the investment, the option value of the investment opportunity should equal the value of the forgoing option to invest, which at the critical point is the difference between the value of the investment and the actual cost of the investment, hence the *value-matching condition*

$$F(V^*) = V^* - I \qquad (13)$$

In addition, the slope of the tangent to the option value line should equal that of the tangent to the return on the investment line at the critical point V^*, hence the smooth-pasting condition is derived by differentiating both sides of the above value-matching equation

$$F_{V^*} = (V - I)_{V^*} = 1 \qquad (14)$$

The relevance of these three boundary conditions can be examined graphically by looking at *Figure 1*, which illustrates the value of the investment opportunity, $F(V)$, with respect to the value of the project, V. For V less than V^*, the value of the option to invest is greater than the expected present value of future profits from the project less the cost of investment, and it is optimal for the firm to wait. As V approaches V^* from the left hand side, the value of the option to invest approaches V^*. As soon as V reaches V^*, it is optimal for the firm to decide to invest, giving up the value of the option to invest in return for the expected net present value of the project.

In the language of dynamic programming, V^* is the *optimal stopping*. The range value of V between $[0,V^*)$ constitutes the *continuation region*. *Continuation* means waiting, *stopping* means investing, and the expected value of future profits from the project minus the cost of investment is called the *termination payoff*. The continuation region is bounded between 0 and V^*, and $F(V)$ is bounded between 0 (*lower boundary condition*) and $V^*- I$ (*value matching condition*). At V^*, the tangents to the curves $F(V)$ and $V - I$ must tend to coincide, and the two curves are said to "highly contact", hence *smooth pasting condition*.

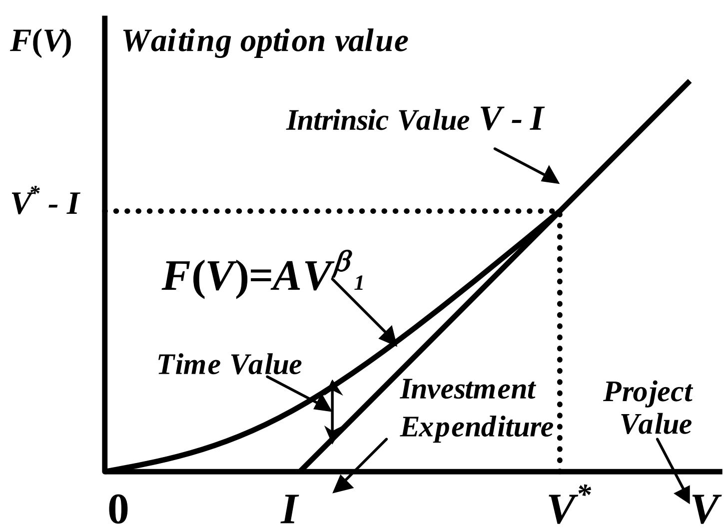

Figure 1: The Value of an Investment Opportunity, *F*(*V*)

Like the fundamental Black-Scholes partial differential equation, our differential equation

(11) can have analytical solutions only when the given economic conditions are satisfied. In our case, the boundary conditions ensure the uniqueness of the solution if any, and an analytical solution can be found by a simple substitution. We notice that Equation (11) is homogenous, then by substitution we can verify that the general solutions[5], $F(V)$, of the simultaneous differential equations (11), (12), (13), and (14) satisfies

$$F(V) = AV^{\beta_1} + BV^{\beta_2} \tag{15}$$

where A and B are constants; and β_1 and β_2 are the roots of the following fundamental quadratic equation

$$f(\beta) = \frac{1}{2}\sigma^2\beta(\beta-1) + (\rho-\delta)\beta - \rho = 0 \tag{16}$$

Solving this equation gives

$$\beta_1 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} + \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} \quad > 1 \tag{17}$$

$$\beta_2 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} - \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} \quad < 0 \tag{18}$$

The coefficient of β^2 of the fundamental quadratic function is positive so the corresponding graph is convex with $f(\beta=0) = -\rho < 0$ and $f(\beta=1) = -\delta < 0$, i.e. as long as $\sigma \neq 0$ (given by our assumption), this quadratic function always intersects with the horizontal axis at two points satisfying $\beta_2 < 0 < 1 < \beta_1$.[6] The free boundary condition (12) excludes the component BV^{β_2} as β_2 cannot take on the negative value or B should be equal to zero, thus

$$F(V) = AV^{\beta_1} \tag{19}$$

Substituting this result into (13) and (14), we get all the required solutions

$$V^* = \frac{\beta_1}{\beta_1 - 1} I \tag{20}$$

$$A = \frac{V^* - I}{(V^*)^{\beta_1}} = \frac{(\beta_1 - 1)^{\beta_1 - 1}}{\beta_1^{\beta_1} I^{\beta_1 - 1}} \tag{21}$$

We are interested in how the changes in σ would affect the change in β_1 and thus, changes in the optimal stopping, V^*. We take the total derivatives at β_1 of both sides of the quadratic equation (16) with respect to σ, and examine the results:

$$\frac{\partial f}{\partial \beta_1}\frac{\partial \beta_1}{\partial \sigma} + \frac{\partial f}{\partial \sigma} = 0 \tag{22}$$

Note that $f(\beta)$ is an increasing function at β_1, so $\frac{\partial f}{\partial \beta_1} > 0$. This, together with (22) and the fact that $\beta_1 > 0$ gives:

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[5] The general solutions require that (11) is an identity meaning it is necessary that the identity is satisfied with all possible values of V.

[6] If x_1 and x_2 are the roots of the function $f(x)=ax^2+bx+c$, and $af(0)<0$ and $af(1)<0$, then the condition $x_1<0<1<x_2$ is always satisfied with $\forall$ a, b, c.

$$\frac{\partial f}{\partial \sigma} = \beta_1(\beta_1 - 1)\sigma > 0 \Rightarrow \frac{\partial \beta_1}{\partial \sigma} < 0 \qquad (23)$$

Dixit and Pindyck (1994) discuss the investment uncertainty relationship by analysing the optimal value to exercise the waiting option to invest, V^*. $V^* = \frac{\beta_1}{\beta_1 - 1} I$ is greater than I with β_1 greater than 1. The larger is β_1, the smaller $\frac{\beta_1}{\beta_1 - 1}$ is, hence the smaller the difference between V^* and *I*. Inequality (23) tells us that β_1 decreases as σ increases, and therefore $V^* = \frac{\beta_1}{\beta_1 - 1} I$ increases. This means that the optimal stopping, V^*, is an increasing function with respect to the uncertainty variable, σ. In other words, a higher level of uncertainty over future values of *V* makes the larger difference between V^* and *I*, which means firms will require larger excess return before deciding to incur irreversible investment expenditure, *I.* The larger excess return is required to compensate for the opportunity cost of investing now that is foregone when the firm invests. An increase in uncertainty raise that opportunity cost of investing now, hence increase the full cost of investing in a marginal unit of capital. With higher full marginal cost of investment, *ceteris paribus*, firms will reduce investment.

3. Data Description and Methodology

Emerging markets are the objects of investigation. We choose Thai companies as the target sample for our empirical investigation into the implications of the real options approach to investment decisions. There are two reasons that influence our choice of the target country. First, while empirical studies on company investment in developed countries are profuse, these types of studies are rare in developing countries and Thailand is not an exception. Second, whereas market institutions are weak or even poor and fragmented in other developing countries, Thailand's relatively developed system of state governance allows for an effective monitoring of firms' operations, thus, the data collected are more reliable as compared to other developing countries. Finally, Thailand's stock exchange is fairly developed and the availability of accounts data for listed companies covers a fairly large number of firms over a relatively long period before the global subprime debt crisis.

We choose the time frame before the global subprime debt crisis to avoid the impact of credit booming and investment surge just before the global crisis and prolong credit crunch and economic bust after the global crisis. An unbalanced panel of 283 listed firms on the Stock Exchange of Thailand from 15 December 1989 to 15 December 2002, extracted from Thomson Reuters Datastream with a total of 1980 observations are used to estimate the probit models of investment to measure the sensitivity of investment to uncertainty and irreversibility.

Our panel is highly unbalanced due to firms' entry and exit during the sampling periods. The use of unbalanced panel data allows the use of much larger sample and lessens the impact of self-selection of firms in the sample. Liang and Zeger GEE estimator can accommodate unbalanced panels with minor changes. The population average Generalised Estimating Equation (GEE) method, developed by Liang and Zeger (1986), is used because of its valuable statistical properties. Consistent

GEE estimates can be obtained under weak assumption about the actual correlation among a subject's observations (Liang and Zeger, 1986).

Using the implication of the real options approach we postulate the following testable hypotheses: i) uncertainty has a negative impact on *positive* fixed investment; ii) firms with more irreversible investment will be relatively more sensitive to uncertainty than firms with more reversible investment; hence the negative impact of uncertainty on investment is stronger for firms with more irreversible investment and lower for firms with more reversible investment.

Disinvestment is not the focus of this research. Our concern is to examine the implications of real options research on investment, particularly the impact of uncertainty and irreversibility to investment. Theoretically, uncertainty and irreversibility widen the area of inaction. Investment is triggered when marginal returns reach a hurdle level that is grossly higher than the usual neoclassical marginal costs. Disinvestment is made only when marginal returns is below a threshold that is lower than the variable costs. The difference between the thresholds under real options and the neoclassical ones is defined by uncertainty and relevance assumptions about the irreversibility nature of investment or disinvestment. For the present research, our focus will be placed on positive investment, which will be examined in the next section.

New investment can be better defined using the net of new capital purchase and sale of existing capital minus the normal depreciation. For our data set, data on sale of capital is not available so we opt for another approximate measure of investment. Investment is defined as the difference between the net fixed assets, K_{it}, of two consecutive years. We are more interested in the investment, which is likely to be irreversible. Therefore, working capital and current asset is not of interest for our purposes. Capital expenditure in terms of fixed assets is appropriate to serve our goals. We then define an investment dummy, DI_{it}, which receive the value of 1 if firms make positive investment and 0 otherwise, and use the population average Generalised Estimating Equation (GEE) method developed by Liang and Zeger (1986) to estimate the corresponding probit equations and analyse the investment uncertainty relationship and its sensitive response to irreversibility.

The explanatory variables chosen for our investment models are based on the evidence of previous company investment research and the implications of real options approach to investment. The natural logarithm of market capitalisation measured by the share price multiplied by the number of ordinary shares in issue is used as a proxy for firm size. A measure of Sales Growth uses the changes in the natural logarithm of total sales between two consecutive periods, ΔLnS_{it}. When the changes in the total of sales are small, this measure is approximately equal to the percentage growth in total sales.

Volatility of the stock market returns of individual firms, U_{it}, is used as a representative measure of firm-level uncertainty. Three year rolling standard deviation of company monthly stock returns (measured by the changes in logarithms of stock return index between two consecutive periods) is used as a measure of volatility. For year *t*, the monthly stock returns are 36 observations taken from year *t-2*, *t-1*, and *t*. The use of the standard deviation of stock returns as an uncertainty proxy enables us to capture the effects of all other factors in one uncertainty measure. Irreversibility is modelled using the total debt and leasing capital.

A reversibility dummy, REV_{it}, which receives the value of *1* if the ratio of total debt and leasing capital to the total fixed capital is larger than the median of the whole sample, indicating more reversibility; and *0* otherwise, indicating more irreversibility, is constructed. The reversibility dummy interacts with uncertainty to examine the theoretical effects as suggested by the real options approach.

The real options literature and other literature on irreversible investment show that firms with more irreversible investment will be relatively more sensitive to uncertainty than firms with more reversible investment; hence the negative impact of uncertainty on investment is stronger for firms with more irreversible investment and lower for firms with more reversible investment. We will include REV_{it} in our regressions to examine this theoretical prediction.

4. Estimation Results

We focus only on positive investment and examine the impact of uncertainty and irreversibility on investment using the standard limited dependent variable regressions, namely the probit models, using the accumulative normal distribution function. The Generalized Estimating Equations (GEE) population-averaged model developed by Liang and Zeger (1986) is used to estimate the probit models.

Table 1 presents the estimation results for the probit models. Heteroskedasticity-robust standard errors are reported to adjust the impact of heteroskedasticity. The assumption that disturbance terms are serially correlated following the AR1 stochastic process is plausible but adjustment for serial correlation does not generally change the interpretation of final results. In fact, consistent GEE estimates can be obtained under weak assumption about the actual correlation among a subject's observations (Liang and Zeger, 1986). Relaxing the assumption of AR1, however, consistently improves the significance of all regressors throughout all regressions. If the factors are found significant with the adjustment for serial correlation, they are consistently significant and do not change signs in all other robust regressions.

Firm size is positive and significant in our censored regressions, confirming it is an important investment determinant. The number of observations of zero or negative investment (1094) outnumbers that of positive investment (886) in our sample and the relationship between sales and investment is insignificant for positive investment. This means disinvestments prevail during the estimation period. Firms may reduce their capital stock for reasons other than sales. One reason is the low capacity utilisation during the sampling period as suggested by Dollar and Hallward-Driemeier (2000), Hallward-Driemeier (2001). Low capacity utilization induces firms to disinvest regardless of the sales situation.

Sales growth demonstrates its significance profile. It is marginally significant for both the probit models, and strongly significant when the assumption over serial correlation is relaxed. This is a weak indication that firms with positive investment place more importance to ex-post sales growth as a proxy for demand growth.

The regression results indicate a strongly significant investment-uncertainty relationship for the uncertainty proxies calculated on the basis of three-year monthly stock returns. Censored sample examining positive investment finds a negative and significant relationship between investment and uncertainty. This result is consistent with Ferderer (1993), Leahy and Whited (1996), and Pattillo (1998), Bloom (2009), and Bloom *et al* (2011).

Table 1: The Impact of Uncertainty and Irreversibility on Investment

DI_{it}	(i) Probit	(ii) Probit-AR1
U_{it}	-.5912** (.1529)	-.5782** (.1517)
$REV_{it}*U_{it}$	.3409** (.0967)	.3446** (.0971)
$Ln(MV_{it})$	.1658** (.0231)	.1695** (.0241)
$\frac{\Delta Ln(S_{it})}{K_{it-1}}$	38249** (15586)	38482# (20483)
z_1 z_2	96.49(4)** 58.78(8)**	90.46(4)** 58.31(8)**

(**Significance at 1% level; *Significance at 5% level; # Significance at 10% level)

Sample: Period: 1994-2002; Number of firms: 283; Total number of observations: 1980 (Unbalanced panel; some observations are missing due to firms enter and exit, some others are lost in regressions due to lags and differences)
i) Time dummies are included in all regressions. Number of positive investment observations, represented by DI_{it} as 1 is 886. Number of non positive investment, represented by DI_{it} as 0 is 1094 (some observation are dropped by the adjustment for AR1 disturbance terms).
ii) Equations estimated using STATA's Generalized Estimating Equations (GEE) population-averaged model. Heteroskedasticity-robust standard errors in brackets. Columns (ii) show estimated results adjusted for serial correlation assuming to follow an AR1 stochastic process.
iii) $z_1(k)$ is a Wald test of joint significance of the reported coefficients while $z_2(k)$ is a Wald test of joint significance of the time dummies, both asymptotically distributed as under the null hypothesis of no relationship.

One important implication of the real options approach to investment decisions is the nature of the irreversible investment-uncertainty relationship. If investment is reversible, firms have much more flexibility with regards to their decisions to invest as they can reverse their investment decisions at any time to restore resources if the market turns adversely after the decisions have been made. Given time flexibility, irreversibility is the other factor that will change the investment behaviour of firms facing uncertainty. Firms with more irreversible investments will be more likely to hesitate to make immediate investment decisions at a given level of uncertainty. Firms with less irreversible investments or more reversible investments will be relatively less sensitive to uncertainty. Thus a study of the relationship between irreversibility, uncertainty and investment will provide useful insights into the investment behaviour of firms.

The real options implications indicate that firms with irreversible investments will be more responsive to uncertainty than firms with less irreversible investments when making investment decisions. We examine explicitly the relationship between irreversibility, uncertainty and investment, to check the validity of this hypothesis. We include the reversibility dummies, REV_{it} defined as slope dummies to interact with uncertainty proxies, U_{it}, to see if irreversibility would influence the sensitivity of investment to uncertainty.

The estimates and significance of firm size and ex-post demand growth is stable and consistent as in all regressions. The inclusion of the slope reversibility dummy, REV_{it}, improves the performance of uncertainty variables significantly. The estimated coefficients on both uncertainty and the interaction of uncertainty with reversibility dummy have the correct signs and are highly significant at 1% level.

5. Concluding Remarks

Thailand's firm-level panel data evidence supports the real options theory of investment and other theories on irreversible investment. Our findings suggest that investment is statistically responsive to uncertainty. We find evidence of the negative relationship between uncertainty and positive investment, suggesting uncertainty depresses investment. Firms under uncertainty, *ceteris paribus*, make less investment than it otherwise would do. If our proxy for irreversibility is valid, our findings suggest real options would play a role in the investment-uncertainty relationship. Firms with more irreversible investment are more responsive to uncertainty than firms with more reversible investment. Firm size is also found to be a significant factor that determines investment in Thai firms.

These insights have implications for firm managers in preparing their capital budgeting and carrying out a series of option-like managerial operations, as well as for policymakers in issuing policies to induce investments. In the traditional NPV model, non-diversifiable risk has an impact on investment decisions by affecting the cost of capital and the discount rate. Firms should raise their awareness of the impact of uncertainty when evaluating their investment and making their investment decisions. Policy makers should be aware that reducing uncertainty might sometimes be more important than other investment incentives. Stability and credibility may have a larger impact than tax incentives or reduction in interest rates.

Thailand's panel-data evidence is our central contribution to the research of real options. The real options approach forms the building block on which empirical methodology is constructed and the results are explained. However, other theories on irreversible investment can also equally be used to explain our results. In fact, as discussed earlier, once the opportunity cost of the forgone waiting option is accounted for and the neoclassical theory on investment is modified to include that opportunity cost, the two theories can be considered as equivalents. Able and Eberly (1994) incorporate both adjustment cost and irreversibility in an extended adjustment cost model of investment. Able and Eberly (1996) examine the costly irreversibility of investment within the framework of the extended concept of Jorgensonian user cost of capital. In both of the papers, they find an equivalent result to the real options approach. In the presence of irreversibility, the wedge between purchase and sale prices of capital creates a range of inaction between the upper entry trigger and lower exit trigger, which is wider than the range of inaction under reversibility. The optimal investment policy is to purchase and sell capital to prevent the marginal profitability of capital from leaving this range. Thus, the modified adjustment cost models or the modified Jorgensonian user cost of capital can explain our results equally well as the real options approach.

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