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Investment of rice mills in Vietnam

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Chapter 6

Investment under uncertainty

6.1 Introduction

Firms are generally uncertain about the future. The uncertainty about the future is likely to affect investment decisions of firms. The theoretical literature on the relationship between uncertainty and firm investment is extensive and contains different points of view: greater uncertainty can lead to either less or more investment. Neither is the empirical literature conclusive about the sign of the relationship between uncertainty and firm investment. Yet, most of the empirical studies have found adverse effects of uncertainty on firm investment.

This chapter is set up to survey the literature on firm investment under uncertainty. It serves to provide a background to our empirical study of the investment-uncertainty relationship in the context of private RMs in the MRD (see Chapter 9). The rest of this chapter is organised as follows. Section 6.2 is devoted to discussing the real options approach to investment, which implies that firms are flexible with respect to their investment decisions. Section 6.3 investigates the empirical evidence on the relationship between uncertainty and firm investment. Section 6.4 concludes this chapter.

6.2 The real options approach to investment

The theoretical literature on the relationship between uncertainty and firm investment has a relatively long history and includes two main strands of theory: the traditional theory and the real options approach to investment. The traditional theory contains two types of models: one type that does not take account of adjustment costs of in-

vestment and the other that does; adjustment costs are the costs involved in the purchase, the instalment, and the resell of capital goods.¹⁰⁰ In this section, we will discuss briefly the traditional models and will pay more attention to the real options approach to investment.

6.2.1 *A brief overview of the traditional models*

The traditional models on uncertainty and firm behaviour that exclude adjustment costs mainly study the effect of uncertainty on the optimal output/input level of firms rather than on investment. These models include Sandmo (1971), Leland (1972), Holthausen (1976), McKenna (1986), *etc.* According to these models, if a firm can instantly and costlessly adjust its capital stock (*i.e.*, adjustment costs is absent), its investment decision is fundamentally a static decision in which the marginal product of capital is equal to the user cost of capital. This outcome is similar to the net present value (NPV) rule. The NPV rule maintains that an investment project should be accepted if the present value of its expected future cash flows, which is usually estimated using the weighted average cost of capital (WACC) as the discount rate, is larger than its investment cost. The discount rate should be considered as a function of the uncertainty facing the firm or its investment projects; therefore, this discount rate has to be adjusted to account for uncertainty. The risk-adjusted NPV rule suggests that an increase in cash-flow uncertainty, with constant expected cash flow levels, will lead to a decreasing investment level (because of decreasing net present values of investment projects).

The traditional investment models without adjustment costs take for granted the assumption that firms can instantly and costlessly adjust to their optimal capital stock. This assumption may not be very realistic because it is normally costly for firms to adjust their capital stock to optimal levels. Thus, adjustment costs should be accounted for. There are models that include adjustment costs like Hartman (1972), Pindyck (1982), Abel (1983), among others. These models, assuming that the uncertainty variable follows a Wiener process,¹⁰¹ derive diagrams or expressions for the optimal rate of investment. Since the optimal rates of investment derived by these models include the uncertainty variable, it is possible to use them to study the effect of uncertainty on firm investment.

The traditional investment theory is useful in studying the effect of uncertainty on the optimal level of output/input as well as on firm investment. Yet, due to poor performances of the empirical studies that follow this theory, it has been reconsidered.

¹⁰⁰ For a comprehensive discussion about adjustment costs, see, *e.g.*, Lensink *et al.* (2001).

¹⁰¹ The Wiener process, also known as Brownian motion, is a method to simulate the volatility of a random variable. This process will be discussed in more detail in Section 6.3 of this chapter.

In the course of reconsidering this theory researchers came up with the real options approach to investment. This approach argues that firms may be flexible with respect to their investment decisions, as will be discussed below.

6.2.2 Background of the real options approach to investment

The real options approach to investment maintains that making a real investment decision is similar to exercising a financial option and that investment opportunities may include options for future follow-up decisions. In particular with respect to irreversible investment in the face of uncertainty, the following features apply:

- First, part or all of the investment cost is sunk.
- Second, economic environments are volatile and uncertain. Under such conditions, firms do not know which direction the economic environments will develop. However, because information evolves gradually, firms will learn more about the future as time passes.
- Finally, since investment opportunities may generally not disappear if they are not taken immediately, these opportunities represent options that need not be exercised immediately.

The following subsections will review the most common real options, without restricting ourselves yet to the case of irreversible investment. This case will be considered later in Subsection 6.2.4.

6.2.3 A description of the real options

The real options that a firm can use is of different types, such as the option to wait, the option to alter the scale of operation (*i.e.*, to expand or to contract), the option to abandon, the option to switch input/output, the option to grow, *etc.* (Trigeogis, 1996). The specific nature of the investment opportunity determines the types of real options that may be involved.

A firm that contemplates an investment opportunity holds an investment option analogous to an American financial call option.¹⁰² A financial call option is a right but not an obligation to buy a financial asset at a preset price, *i.e.*, the strike or exercise price. The cost of the investment (the current purchase price of the physical capital) is akin to the exercise price of the financial call option. If the firm decides to invest, it will exercise the investment option. Given the fact that the investment decision can be postponed, it can equally be maintained that the investment opportunity in-

¹⁰² For a more detailed discussion of the similarities between an investment opportunity and a call option, see, *e.g.*, Trigeogis (1996), Luehrman (1998).

cludes an option to wait. If the firm decides to invest, it kills the option to wait, consequently giving up the possibility to wait for more precise upcoming information.

A firm that has invested, *i.e.*, not having exercised or having killed the option to wait, may be able to abandon later by reselling the invested capital in second-hand markets. In this case, the firm holds a real (investment) option identical to an American financial put option. A financial put option is a right but not an obligation to sell a financial asset at a preset price, the strike or exercise price. The resale price of the invested capital is analogous to the exercise price of the put option. Unlike a standard financial asset, the invested capital is susceptible to some problems that may reduce the possibility to resell it as well as its resale price. The first problem stems from specificity. Since the installed investment may not be usable for any other purpose, it cannot be resold at its purchase price (minus depreciation) but probably at a lower price. Second, once the capital is installed, it is considered as used. Therefore, the reselling of the installed capital will be subject to a “lemons” problem.¹⁰³ In this case, the “lemons” problem implies that the buyer does not have the same information about the quality of the installed as the owner does, so the buyer is willing to pay only an average price for it. The owner of the installed capital has to accept the offered price or withdraw from the market. The owners of above-average quality goods will then leave the market, since the average price of the good in the market is too low for them. This leaves the market with a supply of only less-than-average quality goods. The third problem concerns the efficiency of second-hand markets for the invested capital. If the markets do not function well, it may be difficult for firms to resell their invested capital, or the invested capital can only be resold at a price lower than what it deserves.

A firm that has invested can also alter, *i.e.*, expand or contract, the scale of operation later. The firm would expand the scale of operation if the market conditions improve. This possibility is equivalent to an option to expand. The expandability involves a call option. If the market conditions become unfavourable, the firm would contract the scale of operation by, *e.g.*, halting part of the production. This possibility resembles the option to contract, analogous to a financial put option. Afterwards, if the market conditions recover, the firm can reactivate the halted part of the production, implying the existence of another call option.¹⁰⁴

A firm that has invested to produce a certain type of products or to use a certain type of inputs can later switch to other products or inputs of which prices turn out

¹⁰³ This problem was introduced in Akerlof (1970). See also Section 5.2 of Chapter 5.

¹⁰⁴ This is characterised as compound option (Panayi and Trigeorgis, 1998; Hull, 2000). Compound options are those options whose exercise brings forth additional options as well as generating cash flows (Panayi and Trigeorgis, 1998). According to Hull (2000), there are four main types of compound options: a call on a call, a put on a call, a call on a put, and a put on a put. The one described above is a call on a put.

to be more favourable for the firm. This option (to switch) resembles a financial call option. Since this option allows firms to retain the invested capital, it may be valuable if the purchase price of the investment capital is increasing.

Real options are embedded in many decisions of the firm, particularly investment decisions. Each option has benefits and costs. In general, the benefits of a real option result from its ability to help the firm to limit the adverse effects of the downturn side and to make use of the advantages of the upturn side of an economic development. The costs of a real option includes the profits forego in case the firm adopts the option. If the benefits of exercising an option are larger than the costs, the firm should exercise the option.

As we have just discussed, firms have to deal with a collection of real options of which some are extinguished or generated after an alternative has been selected. Therefore, in order to make proper investment decisions firms have to balance the benefits against the costs of this collection, which does not seem to be straightforward.

6.2.4 *Real options and firm investment*

This subsection will try to explain how the real options affect firm investment and explore the net effect of the real options collection on firm investment. It will argue that the net effect may be ambiguous because the real options collection comprises options that have different, even opposing, effects on firm investment.

A fundamental question to start with is whether under uncertainty firms wait or invest immediately when a valuable investment opportunity appears. It is likely that firms will opt for waiting; in other words, they will keep the investment option alive. Keeping the investment option alive, or exercising the option to wait, is valuable. The value derives from two sources, according to Luehrman (1998). The first source is the time value of money on the deferred expenditure (to acquire the investment) that would have been incurred if not waiting, assuming that investment is constant. Second, waiting enables firms to take part in good outcomes (if things improve) and precludes them from being involved in bad outcomes. Moreover, McDonald and Siegel (1986) show that the higher the degree of uncertainty, the higher the value of the option to wait. The positive relation between the degree uncertainty and the value of the option to wait is due to the asymmetry in this option's net payoffs. This asymmetry works as follows.¹⁰⁵ Under higher uncertainty, it is possible that the underlying variable (*e.g.*, output demand or price) rises up to high levels, so the net payoff from

¹⁰⁵ In general, this argument refers to the basic relationship between the value of a call option and the uncertainty (volatility) of a option's underlying asset: the option value is positively related to this uncertainty.

exercising the option to wait becomes larger. If the underlying variable falls, one can lose (when killing the option) only what has been paid for the option. Therefore, uncertainty will have a negative effect on investment through the channel of the option to wait.

The negative effect of the option to wait on investment may change if the option to abandon comes in. The option to abandon brings about extra benefits because it allows firms to abandon or reverse the investment so as to reduce the adverse effects of a downturn. Hence, this option encourages current investments. Yet, the effect of this option on investment depends on the degree of reversibility. The degree of reversibility of an investment is conditional on its specificity, the “lemons” problem, and the functioning of the second-hand markets, as discussed previously in Subsection 6.2.3. If the investment is totally reversible, *e.g.*, the resale price of the investment is equal to its purchase price, the option to wait may not be effective. If the investment is not totally reversible, the investment behaviour of firms depends on both the possibility to resell the invested capital and its resale price, two elements of an investment’s irreversibility.¹⁰⁶

The killing of the option to wait, or exercising the option to invest, makes the option to expand available to firms. Since the option to expand enables firms to further invest later if the future turns out to be more favourable, it may discourage the current investments. Given the presence of the option to expand, firms need to decide on how much to invest now and in the future. As for this type of investment decision, the price of investment capital is a concern. If the future purchase price of the investment capital, *i.e.*, the future exercise price, is to increase over time, firms may invest more now and may not expand in the future. Otherwise, they would invest less now and expand later. However, the timing of the future expansion and the future purchase price are usually unknown to firms when making investment decisions. This element complicates the modelling of the investment behaviour of firms.

The option to contract production is also created after the option to wait has been killed. Unlike the option to expand, this option is valuable only if a downturn occurs because it helps firms to escape the losses resulting from the variable costs of production. For instance, if its output price goes down, firms can close part or all of their production lines. The option to contract in turn brings in the option to reactivate.

It can be inferred from the above discussion that the net effect of the collection of real options on firm investment may be ambiguous. Theoretical models have been developed to reveal the net effect of this collection on firm investment. Among them is Abel *et al.* (1996). Abel *et al.* consider a partially irreversible investment with its resale price being less than its purchase price. They also allow for a limited expandability by assuming that the purchase price of physical capital is to increase over

¹⁰⁶ In Chapter 9, we will use these two elements of irreversibility to construct our irreversibility variable.

time. This assumption implies an additional opportunity cost of waiting apart from the foregone profits, which reduces the value of the option to wait. This model introduces two sorts of real options: call and put. The call options include an option to wait and an option to expand. The put option includes an option to abandon (or disinvest). Given the presence of these options, uncertainty affects investment in two opposite directions. Uncertainty negatively affects investment because it increases the value of the call options; investing means losing (part of) the value the call options. In contrast, uncertainty positively affects investment because it raises the value of the put option; investing means “activating” the valuable put option. Abel *et al.* conclude that the net effect of uncertainty on investment is ambiguous, depending on the degree of irreversibility (represented by the resale price of the investment capital) and the expandability. The higher the degree of irreversibility and expandability, the stronger the negative effect of uncertainty on investments is.

6.2.5 Some further considerations

The discussions in the previous subsections provide a good background for our empirical study. However, in our opinion some further considerations that are also relevant for studying the investment-uncertainty relationship should be addressed.

In the standard real options approach to investment under uncertainty, it is assumed that the firm makes investment decisions regardless of competitive interactions. In practice, competition can affect the investment-uncertainty relationship. According to Caballero (1991), imperfect competition may intensify the negative investment-uncertainty relationship. A monopolistic firm may easily postpone its investment because the investment opportunity is always available for it to take. This argument, probably to a lesser extent, may also be applicable to an oligopolistic firm. In contrast, if a firm operating in a competitive environment waits too long, its competitors will seize the investment opportunity. Therefore, the firm has to invest quickly in order to preempt the rivals (Abel and Eberly, 1994; Lambrecht and Perraudin, 2003). In this case, the value of the option to wait becomes less (Grenadier, 2002).¹⁰⁷ As a result, competition reduces the adverse effect of uncertainty on firm investment.

Firm size may be another aspect that should be considered when studying the uncertainty-investment relationship. Small firms may have inadequate managerial ex-

¹⁰⁷ Grenadier (2002) shows that if competition is severe enough to force the firm to invest immediately (*e.g.*, if the number of firms in the industry is huge), the value of the option to wait will become zero, and the NPV rule will apply. Luehrman (1998) also argues that when the final decision on a investment project can no longer be deferred, the project’s option value and NPV will be the same.

pertise that limits their ability to reduce adverse effects of possible changes. This would suggest that investment of small firms is likely to be more adversely affected by uncertainty. In contrast, Joaquin and Khanna (2001) assume that firms are able to abandon investment at a cost that is increasing with size. This assumption may be reasonable to the extent that larger firms tend to have greater abandonment costs regarding individual investment projects.¹⁰⁸ If abandonment costs are increasing with firm size, similar investment projects may be deemed as more irreversible by larger firms than by smaller ones. Therefore, uncertainty, through the channel of irreversibility, may more negatively affect investment by larger firms than that by smaller firms. Thus, the effect of firm size on the uncertainty-investment relationship appears to be ambiguous according to these arguments. This leaves room to study this issue in the case of Vietnam.

6.2.6 *Summary*

The real options approach to investment improves the understanding of firm investment under uncertainty. Nonetheless, this approach has shown an ambiguous sign of the relationship between uncertainty and firm investment: greater uncertainty can lead to either less or more investment. Such an ambiguity invites empirical studies. As revealed by the theoretical work, irreversibility, competition, and firm size are among the important factors affecting the investment-uncertainty relationship that empirical studies should take into account. We will examine the evidence found by empirical studies on the investment-uncertainty relationship in Section 6.3 below.

6.3 **Empirical evidence**

This section discusses the evidence emerging from the empirical studies on firm investment under uncertainty. Since it is not possible to discuss all the relevant studies, we just focus on those that concentrate on the factors that are theoretically assumed to affect the investment-uncertainty relationship, *i.e.*, irreversibility, competition, and firm size.¹⁰⁹ A summary of the findings of these empirical studies is also given in Appendices 6.1-6.4 at the end of this chapter.

In general, the empirical evidence appears to endorse adverse effects of uncertainty on firm investment. For instance, Driver *et al.* (1996) convey that the most common result is that demand uncertainty discourages firm investment, especially in the presence of irreversibility. This result, according to Driver *et al.*, is more obvious

¹⁰⁸ This assumption is supported by Weiss (1990).

¹⁰⁹ Even with this restriction, the list of studies to be discussed below may not be exhaustive.

if competition is imperfect. Bo (2001) reports that 18 out of 21 studies, which she is aware of, find negative relationships between uncertainty and firm investment.

6.3.1 Uncertainty measurement

In studying the effect of uncertainty on firm investment, an important issue is how to measure uncertainty because uncertainty is generally unobservable. Several methods to measure uncertainty have been applied.¹¹⁰

A popular method to measure uncertainty is to use the variance of the unpredictable part of the stochastic variable. This method follows three steps: (i) constructing a forecasting equation for the underlying variable, (ii) estimating the forecasting equation to obtain the unpredictable part of the fluctuations of the variable, which is called the estimated residuals, and (iii) computing the variance or standard deviation of the estimated residuals and use it/them as an uncertainty measure for the variable under consideration (Bo, 2001). This method has been applied by, *e.g.*, Aizenman and Marion (1993, 1999), Ghosal and Loungani (1996, 2000), among others.

Another method to measure uncertainty is to employ the variance estimated from the geometric Brownian motion, which is also referred to as Wiener process. This method is used to simulate the volatility of a time-dependent variable. For a project value V that follows a geometric Brownian motion, the stochastic equation for its variation with time t is as follows:

$$dV_t = \alpha V_t dt + \sigma V_t dz,$$

where: dz is an increment process with zero mean and unit variance, α is the drift, and σ is the volatility of V_t . In this equation, the first term of the right-hand side ($\alpha V_t dt$) is the expectation (trend) term and the second term ($\sigma V_t dz$) is the variation term (deviation from the tendency or term of uncertainty). Empirically, σ is used to measure uncertainty. This stochastic process is commonly applied in option pricing theory (see, *e.g.*, Hull, 2000).

Empirical work also uses the Autoregressive Conditional Heteroskedasticity (ARCH) model to measure uncertainty. ARCH is a time series modelling technique that uses past variances and past variance forecasts to forecast future variances. Several studies, *e.g.*, Huizinga (1993), Episcopos (1995), Price (1996), use this model to measure uncertainty.

¹¹⁰ Lensink *et al.* (2001) provide a detailed and comprehensive survey of the methods.

An interesting method to measure uncertainty is to compute the variance or the standard deviation of an underlying variable using expectation data collected through surveys. An appealing feature of this method is that the data contain the decision-maker's perception of uncertainty conditional on his/her own information, meaning that the uncertainty measure should be correlated with the investment plan. In order to apply this method, an important assumption required is that the future outcomes should be described by a subjective probability distribution (SPD). This method is used by a number of studies, *e.g.*, Pattillo (1998), Guiso and Parigi (1999), Lensink *et al.* (2000).

In Pattillo (1998), firm owners were asked for their one-year and three-year expectations about the demand for their firms' output. The owners were requested to assign probabilities, which sum to 100, to a distribution that contains a variety of possible percentage changes in the demand. The distribution, called subjective probability distribution (SPD), looks like the one presented in Table 6.1.¹¹¹ Pattillo computes the subjective variance of the expected demand out of this information and uses this variable (scaled by the previous period's capital stock) as a measure of uncertainty.¹¹²

Table 6.1 Subjective probability distribution (SPD)

<i>Intervals</i>	<i>By what per cent do you expect demand for your product to grow next year?</i>	<i>By what per cent do you expect demand for your product to grow in the next 3 years?</i>
<i>Increase</i>		
More than 30 per cent		
20 to 30 per cent		
10 to 20 per cent		
0 to 10 per cent		
<i>No change</i>		
<i>Decrease</i>		
0 to 10 per cent		
10 to 20 per cent		
20-30 per cent		
More than 30 per cent		
<i>Total points</i> <i>(should add to 100)</i>		

Source: Pattillo (1998).

¹¹¹ A definition of subjective probability distribution is given in Subsection 4.4.2 of Chapter 4.

¹¹² Appendix 9.1 at the end of Chapter 9 will show how to compute the subjective variance of the expected demand out of the information presented in Table 6.1.

Guiso and Parigi (1999) use the information provided by the Survey of Investment in Manufacturing (SIM) and the Company Accounts Data Service (CADS), which reports the SPD of the evolution of the future demand for each individual firm's output. From this information, Guiso and Parigi compute and use both the standard deviation of the expected demand and the variance of the expected growth rate of demand (scaled by the capital stock) as measures of uncertainty.

Lensink *et al.* (2000) carried out a survey over Dutch non-listed firms, which enables to record firms' subjective perception of future sales. By this survey, information about the SPD was obtained. Lensink *et al.* compute the coefficient of variation of the expected sales and use this as a measure of uncertainty.

As we have seen, several methods have been used to measure uncertainty. The choice of which method to use largely depends on the nature of data. Our empirical study on the relationship between uncertainty and firm investment in Chapter 9 will employ the method in which the variance and the standard deviation of an underlying variable are used as measures of uncertainty; the information about the underlying variable was collected through a survey (see Chapter 7).

6.3.2 Uncertainty measures and the investment-uncertainty relationship

Empirical studies have employed the aforementioned methods to construct uncertainty variables using different underlying variables. Leahy and Whited (1996) study the investment of 600 U.S. manufacturing firms over the period of 1981-1987. Using the variance of the firms' daily stock returns to measure uncertainty, Leahy and Whited show that uncertainty has a negative effect on investment of the firms in the sample.

Driver *et al.* (1996) use the data coming from the PIMS database to compute market share volatility and use it as a proxy of demand uncertainty.¹¹³ In this study, the market share volatility of a company is defined as the summed absolute value of the differences between the proportionate time change in its own share, share of competitor *A*, and share of competitor *B*.¹¹⁴ Driver *et al.* find that the demand uncertainty

¹¹³ The PIMS (Profit Impact of Market Strategy) of the Strategic Planning Institute is a large scale study designed to measure the relationship between business actions and business results. The project was initiated and developed at the General Electric Co. from the mid-1960s and expanded upon at the Management Science Institute at Harvard in the early 1970s; since 1975 the Strategic Planning Institute has continued the development and application of the PIMS research. The PIMS database is described in Buzzell and Gale (1987).

¹¹⁴ The formula used by Driver *et al.* to compute the market share volatility reads as follows: $abs(dif(SO-SA)) + abs(dif(SO-SB)) + abs(dif(SA-SB))$, where *abs* and *dif* stand for absolute value and difference, respectively; and *SO*, *SA*, *SB* for natural logs of market share of the company, competitor *A*, and competitor *B*, respectively.

variable has a negative effect on the firms' investment.

Bell and Campa (1997) study the effect of different uncertainty variables (such as exchange rates, input prices, and product demand) on firm investment (including greenfield investments and capacity expansions) in the chemical sector in the United States and the European Union.¹¹⁵ In order to measure exchange rate uncertainty, Bell and Campa use the average level of the IMF trade-weighted exchange rate index. The exchange rate uncertainty variable is defined as the standard deviation of the monthly change in the logarithm of the exchange rate index. Input price uncertainty is measured by the standard deviation of the monthly change in the logarithm of the real oil price. Finally, the product demand uncertainty variable is measured by the standard deviation of the monthly change in the logarithm of the index of world chemical production (national industrial production) for the global (national) specification. Bell and Campa find that the effect of uncertainty on capacity investment varies across these three uncertainty variables. The input price and product demand uncertainty variables have no significant effect on investment for both the United States and the European Union, whereas the exchange rate uncertainty variable has a significant negative effect on investment by chemical manufacturers in the European Union.

Ogawa and Suzuki (2000) empirically analyse the effect of uncertainty on investment of 389 Japanese manufacturing firms over the period of 1970-1993.¹¹⁶ These firms are listed on the Tokyo Stock Exchange. They use the conditional standard deviation of the growth of sales as a measure of uncertainty. Ogawa and Suzuki use three statistical methods to construct the conditional standard deviation of the growth rate of real sales: the ARCH model, the rolling regression model, and the conventional way of computing the standard deviation. Ogawa and Suzuki find that uncertainty has a negative effect on investment if the uncertainty variable is constructed using the conventional standard deviation measure and the ARCH model.

The empirical studies reviewed in this subsection appear to lend support to the argument that uncertainty may have negative effects on firm investment. However, as mentioned in Subsection 6.2.5, irreversibility, competition, and firm size may play a role in explaining the uncertainty-investment relationship. Therefore, these factors should be considered while studying this relationship. In the following subsections, we discuss the results of the empirical studies that take these factors into account.

¹¹⁵ According to Bell and Campa, "greenfield investments include plants situated where the company has not previously undertaken chemical processing, where the company has maintained a chemical complex but not previously produced the chemical, or where the company has previously produced the chemical but has added a new plant. Capacity expansions include increasing yields through technological changes, production bottleneck removals and new train or line additions to an existing plant."

¹¹⁶ Information about these firms is extracted from a database provided by the Japan Development Bank.

6.3.3 *The investment-uncertainty relationship and irreversibility*

Irreversibility may play an important role in generating negative effects of uncertainty on firm investment. If investment is perfectly reversible, *e.g.*, resale price being equal to purchase price, it should not be negatively affected by uncertainty because firms will not have an incentive to wait. Differently stated, the option to wait is valuable if investment is irreversible. In the empirical studies exploring the nexus between irreversibility and the investment-uncertainty relationship, different proxies for irreversibility are used.

In Bell and Campa (1997), investments in the chemical sectors in the United States and the European Union are split up into greenfield investment and capacity expansion. Since greenfield investment may have a higher sunk cost, it is assumed to be subject to a higher degree of irreversibility as compared to capacity expansion investment. Bell and Campa find that the negative effect of uncertainty, measured by the volatility of exchange rates, is significant for the greenfield investment but insignificant for the capacity expansion.

Goel and Ram (1999) examine investments in different sectors with different degrees of irreversibility: producer durables, residential real estate, and non-residential real estate. Goel and Ram argue that investment in residential real estate may be least irreversible because there may be good markets for residential real estate; investment in machinery and equipment, which constitute the major component of producer durables, seems to be more irreversible since such investment is likely to be firm-specific and/or industry-specific; non-residential real estate may be more irreversible than residential real estate but less irreversible than producer durables because non-residential real estate is firm-specific and/or industry specific only to some extent. Goel and Ram use the five-year moving standard deviation of inflation as a measure of uncertainty and find evidence of a stronger adverse effect of uncertainty on investment by firms in the sectors that have higher degrees of irreversibility.

Goel and Ram (2001) make a distinction between R&D and non-R&D investments with regard to the degree of irreversibility. They argue that R&D investment is subject to a higher degree of irreversibility. Using similar uncertainty variables as in Goel and Ram (1999), Goel and Ram find that a higher degree of irreversibility renders a sharper adverse effect of uncertainty on R&D investment than on non-R&D investment in OECD countries.

Bo (2001) aims to study whether or not firms wait because of uncertainty using information on 77 Dutch firms during the period of 1984-1997. A variable called “wait”, equal to the difference between the threshold and the observed values of profit, is applied. This variable is assumed to be negatively correlated with investment of the firms. Bo uses asset liquidity and the rate of depreciation of capital goods as

indicators of irreversibility.¹¹⁷ She interacts the irreversibility variables with the variable “wait” to study the association between irreversibility and the delay of investment. Bo finds that the variable “wait” has a significant, negative effect on investment and that the interaction term has a positive coefficient, but the coefficient is not significant when asset liquidity is applied. The same result is found when the rate of depreciation is used.

In order to proxy for irreversibility, Ogawa and Suzuki (2000) create an irreversibility variable that takes on a value of one if the firm belongs to the materials industry group and zero if the firm is in the machinery industry group.¹¹⁸ They then interact this dummy variable with the uncertainty variable (*i.e.*, the conditional standard deviation of the growth rate of real sales) and find that this interaction term is negative and significant if the uncertainty variable is constructed using the rolling regressions and the ARCH models. This result would imply that investment is more sensitive to uncertainty for the materials industry group. Ogawa and Suzuki argue that irreversibility also depends on types of shock facing the firm (*i.e.*, aggregate, industry-wide or firm-specific). Firms may find it easier to resell capital goods if shocks are firm-specific than if shocks are aggregate or industry-wide because if aggregate or industry-wide shocks occur, no firm in the industry would risk buying capital goods. Therefore, uncertainty stemming from firm-specific shocks may have less negative effects on investment than that originating from aggregate or industry-wide shocks. Ogawa and Suzuki decompose demand uncertainty into three components: aggregate, industry-wide, and firm-specific. The aggregate uncertainty is represented by the standard deviation of the rate of change on monthly yen-dollar exchange rate for five years; as for the industry-wide uncertainty, the standard deviation of the rate of change on the production index by industry is employed; and the firm-specific uncertainty is given by the residual of the regression relating individual uncertainty to aggregate and industry-wide uncertainty. Ogawa and Suzuki find that aggregate and industry-wide uncertainties exhibit significantly negative effects on investment. Moreover, the absolute values of the coefficient of the aggregate and industry-wide uncertainty are much larger than that of the firm-specific uncertainty. This finding may again confirm the importance of irreversibility in generating negative investment-uncertainty relationships.

¹¹⁷ According to Bo, asset liquidity may indicate irreversibility because firms that encounter difficulties in reselling their capital goods should hold more liquid assets. However, one can also argue that a firm has higher level of liquidity because it may have difficulties in getting access to credit. If so, liquidity may not say much about irreversibility. As for the rate of depreciation of capital goods, the argument is that the higher the rate of depreciation, the faster the sunk costs embedded in capital goods erode, thereby reducing irreversibility.

¹¹⁸ It is not clear from Ogawa and Suzuki why irreversibility is more severe in the materials industry group than in the machinery industry group.

Irreversibility can also be examined by looking at second-hand markets for capital goods, as discussed earlier in Subsections 6.2.2 and 6.2.3. Pattillo (1998), based on a panel data of 200 Ghanaian manufacturing firms over the period of 1994-1995 collected by Ghana Survey,¹¹⁹ calculates and uses the scaled subjective variance of the expected demand as a measure of uncertainty (discussed above). She finds that the coefficient of the uncertainty variable is not significant for the whole sample if the irreversibility variable (*i.e.*, the ratio of the real resale value of the capital stock to its real replacement cost) is not included. With the presence of the irreversibility variable, the variance of the expected demand, *i.e.*, the uncertainty variable, has a negative and significant coefficient.

Guiso and Parigi (1999) use the standard deviation of the expected demand and the variance of the expected rate of growth of demand (scaled by the stock of capital) as measures of uncertainty. They find that demand uncertainty has a significantly negative effect on the sample's investment. Guiso and Parigi (1999) use two proxies for irreversibility: (i) the degree of the access to the second-hand market for installed capital, and (ii) the co-movement with respect to sales of firms in the industry (*i.e.*, the degree of cyclical correlation of firms within an industry).

As for the degree of the access to the second-hand markets for machinery, Guiso and Parigi formulate four alternatives in their questionnaire that reflect an increasing degree of irreversibility of machinery: (i) it can be sold easily without incurring significant losses with respect to its value in use, (ii) it can be sold, but it requires some time to find a buyer, and losses are incurred, (iii) it takes a long time to find a buyer, and one can only be found if the selling drops considerably below value in use, and (iv) there is essentially no second-hand market at all. Based on the information obtained from the questionnaire using this formulation, Guiso and Parigi split the sample into two groups of firms: less and more irreversibility.

Guiso and Parigi base their second proxy for irreversibility on co-movement of sales, *i.e.*, the degree of cyclical correlation of the sales of firms within an industry, and on the argument that a firm's asset reversibility depends on the amount of cash held by other firms in the same industry, which is proposed by Shleifer and Vishny (1992). Shleifer and Vishny argue that if the industry experiences a downturn and if firms in that industry hold small amount of cash, it is difficult for a firm to resell its capital good, leading to high irreversibility for that firm. It can be reasoned that asset illiquidity (or irreversibility) is more prevalent in those industries plagued by common shocks (having high co-movements) than those facing idiosyncratic (firm-specific) shocks (having low co-movement).¹²⁰ Based on the information ac-

¹¹⁹ The Ghana Survey derives from the Regional Programme on Enterprise Development (RPED) organised by the World Bank and from the Ghana Manufacturing Enterprise Survey funded by the U.K government.

¹²⁰ This argument seems to be similar to those of Goel and Ram (2001), Ogawa and Suzuki (2000).

quired from the CADS, Guiso and Parigi construct an irreversibility variable for each firm: $w_{jt} = \frac{x_{jt} - \bar{x}_j}{s_j}$, with x_{jt} being the first difference of the log of the firm's sales in year t , \bar{x}_j the sample mean of x_{jt} , and s_j its standard deviation. Then, firms are grouped into 44 sectors for which w_{jt} is regressed based on a set of year dummies; w_{jt} is used as a measure of aggregate shocks. Sectors that have a higher level of aggregate shocks should exhibit higher R^2 resulting from the regressions. Next, firms are classified as having low or high irreversibility if the R^2 is below or above the median. Using both irreversibility variables, Guiso and Parigi find that the higher the degree of irreversibility, the greater the negative relationship between uncertainty and investment.

In short, the empirical studies have revealed that irreversibility appears to accentuate the adverse effect of uncertainty on firm investment regardless of how it is measured. This may be because if irreversibility is prevalent, it is difficult for firms to get rid of the investments if the economic condition deteriorates, thereby inducing them to postpone investment.

6.3.4 *The investment-uncertainty relationship and competition*

As argued in Section 6.2.4, competition may induce firms to invest quickly in order to preempt investment by existing or potential rivals. Therefore, investment by firms facing strong competition may be less negatively affected by uncertainty. Some empirical studies have worked on this argument.

Ghosal and Loungani (1996) study the effect of price uncertainty on industry-level investment using information from U.S. manufacturing industries. They use a four-firm seller concentration ratio to measure the degree of product competition and to partition 254 industries. Ghosal and Loungani do not find strong effect of price uncertainty for the entire sample. Yet, they find a negative effect of uncertainty on investment for more competitive industries but not for less competitive ones.

Guiso and Parigi (1999) compute and use profit margins on unit price as a proxy of firms' market power. They consider firms with a profit margin above (below) the mean (or median) profit margins of the industry as having more (less) monopoly power. Guiso and Parigi find that the uncertainty variable (*i.e.*, the standard deviation of the expected demand) has negative coefficients for all cases. The coefficient of the uncertainty variable is much smaller (in absolute value) for firms that have low mar-

ket power.¹²¹ This finding appears to support the argument that competition may reduce the negative effect of uncertainty on investment.

6.3.5 *The investment-uncertainty relationship and firm size*

Ghosal and Loungani (2000) study the effect of profit uncertainty on industry-level investment over 330 industries. Based on the information obtained from Gray and Bartlesman (1991) as well as from the Small Business Administration report, Ghosal and Loungani divide the sample into two size groups: small and large. They find that greater uncertainty (about future profits) lowers investment for the full sample of industries. Ghosal and Loungani also discover that the negative effect of profit uncertainty on investment is stronger for the industries that are more dominated by smaller firms.

Lensink *et al.* (2000) aim to examine whether the uncertainty-investment relationship depends on firm size. They use the number of employees to measure firm size. Lensink *et al.* find that uncertainty has a positive effect on investment of small firms, and this relationship is negative for large firms. The explanations for this finding, according to Lensink *et al.*, are: both small and large firms in the sample do not appear to be financially constrained, and sunk costs are much higher for large firms than for small Dutch firms.

6.4 Conclusions

There are two theoretical strands that address the effect of uncertainty on firm investment. One strand is the traditional theory on investment under uncertainty and the other is the real options approach to investment. The traditional theory is helpful in explaining the optimal choice of input and output as well as optimal investment. However, this theory does not seem to be very successful in explaining the investment behaviour of firms because it does not consider the fact that firms have flexibility regarding their investment decisions. The real options approach to investment emerges to account for this fact.

In view of the real options approach to investment, making investment decisions resembles exercising financial options, which has both benefits and costs. In fact, firms have to deal with a collection of real options that derive from the invest-

¹²¹ The results of their study are indifferent with regard to the choice of the splitting criterion, *i.e.*, mean or median profit margins.

ment opportunity. The interaction among these options makes the net effect of uncertainty on investment ambiguous.

The theoretical models developed based on the viewpoint of the real options approach attempt to embrace the effects of both uncertainty and irreversibility on investment. These models find that uncertainty affects firm investment through the real options channel. The dimension of the relationship between uncertainty and investment can be clarified theoretically if the option to wait is introduced. The inclusion of more options complicates the relationship. The net effect of uncertainty on investment can be either positive or negative depending on the value of the real options. The survey of the existing models suggests that, given the presence of irreversibility, uncertainty reduces investment while competition increases it. Moreover, uncertainty may have different effects firm investment depending on firm size.

Given such ambiguous theoretical relationships, empirical work is helpful in understanding true relationships between uncertainty and firm investment. Empirical studies have been carried out to reveal this relationship. Although the empirical models find mixed results, most of them appear to lend support to adverse effects of uncertainty on firm investment given the presence of irreversibility. The adverse effects of uncertainty on investment may be reduced under competition. Firm size may also contribute to shaping the investment-uncertainty relationship; however, the link is less clear, based on the available empirical evidence.

To conclude the theoretical review, it should be mentioned that the possible interaction between uncertainty and financial market imperfections has not been explored. Uncertainty may have an indirect effect on firm investment through its effect on the degree of financial constraint facing the firm, an effect channelled by the mechanism of information asymmetry. The discussions in Chapters 5 and 6 mean that the effects of financial market imperfections and uncertainty on investment will be examined separately in the empirical part of this dissertation.

Appendix 6.1 Summary of the results of empirical studies on firm investment under uncertainty

<i>Study (by year)</i>	<i>Country</i>	<i>Uncertainty measures</i>	<i>Signs of the coefficient of the uncertainty variable</i>
Leahy and Whited (1996)	U.S	Variance of firms' daily stock returns	Negative
Driver <i>et al.</i> (1996)	U.S	Market share volatility	Negative
Bell and Campa (1997)	U.S and E.U	Standard deviation of the monthly changes in the logarithm of the exchange rate index	Negative for the E.U but not for the U.S
		Standard deviation of the monthly changes in the logarithm of the real oil price	Not significant
		Standard deviation of the monthly changes in the logarithm of the index of world chemical production	Not significant
Guiso and Parigi (1999)	Italy	Standard deviation of expected demand	Negative
		Variance of the expected rate of growth of demand	Negative
Ogawa and Suzuki (2000)	Japan	Standard deviation of the growth rate of real sales	Negative

Appendix 6.2 Summary of the results of empirical studies on the uncertainty-investment relationship: the role of irreversibility

<i>Study (by year)</i>	<i>Country</i>	<i>Irreversibility proxies/distinctions</i>	<i>Signs of the coefficient of the uncertainty variable</i>
Bell and Campa (1997)	U.S and E.U	Greenfield investments: higher irreversibility Capacity expansions: lower irreversibility	Negative for greenfield investments but not for capacity expansions
Pattillo (1998)	Ghana	Ratio of the resale value of capital stock to its real replacement cost	Negative if the irreversibility variable is included
Guiso and Parigi (1999)	Italy	Degree of the access to the second-hand market for installed capital Co-movement	The higher degree of irreversibility, the greater the negative relationship between uncertainty and investment
Ogawa and Suzuki (2000)	Japan	Materials industry group versus machinery industry group Aggregate, industry-wide and firm-specific shocks	Investment more sensitive to uncertainty for the materials industry group. Aggregate and industry-wide uncertainty has much stronger negative effects on investment than firm-specific uncertainty does.
Goel and Ram (2001)	OECD countries	R&D investment: high irreversibility Non-R&D investment: low irreversibility	Uncertainty has stronger negative effects on R&D investment than on non-R&D investment
Bo (2001)	Netherlands	Asset liquidity Rate of depreciation	No significant coefficients

Appendix 6.3 Summary of the results of empirical studies on the uncertainty-investment relationship: the role of competition

<i>Study (by year)</i>	<i>Country</i>	<i>Competition proxies/distinctions</i>	<i>Signs of the uncertainty coefficient</i>
Ghosal and Loungani (1996)	U.S	Four-firm seller concentration ratio	Negative effect of uncertainty on investment for more competitive industry
Guiso and Parigi (1999)	Italy	Profit margins on unit price	The negative effect of uncertainty on investment is lower for firms having low market power

Appendix 6.4 Summary of the results of empirical studies on the uncertainty-investment relationship: the role of firm size

<i>Study (by year)</i>	<i>Country</i>	<i>Size proxies/distinctions</i>	<i>Signs of the uncertainty coefficient</i>
Ghosal and Loungani (2000)	U.S	Small and large	Negative for industries dominated by small firms
Lensink <i>et al.</i> (2000)	Netherlands	Number of employees	Positive for small firms, and negative for large firms