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Resolving uncertainty and creating value from the exercise of e-commerce investment options

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Abstract. *This study examines the effect of the resolution of uncertainty on real options exercise decisions with respect to three e-commerce investment options: scale-up, stage and joint investment, and the relationship between exercise of these options and firm performance. The results of a study of 172 public e-commerce investment announcements show that resolution of external (exogenous) and internal (endogenous) uncertainty has a significant effect on option exercise decisions. However, the results also imply that simply waiting without investment in active learning does not create significant value from real options. The key differentiator is how a firm resolves endogenous uncertainty as this endows it with the ability to successfully undertake the information technology investment and exploit the economic opportunity implied by the resolution of exogenous uncertainty. Furthermore, our results imply that different options should be used to manage situations involving certainty of loss on one hand and severity of loss on the other hand. Thus, it is important for firms to make the right choices when using options-based investing to manage risk. We suggest that, perhaps, managers need to maintain a portfolio of options to manage the two dimensions of risk simultaneously.*

Keywords: uncertainty, organisational learning, real option, exercise decision, firm performance

1. INTRODUCTION

Real options analysis has been suggested as a promising theoretical perspective for evaluating irreversible investment decisions made under uncertainty as it captures managerial flexibility concerning the structuring of these investments (Dixit & Pindyck, 1994). This approach is suited to evaluating the pay-off of information technology (IT) investments because by exploiting managerial flexibility, inherent risks in undertaking IT investments can be minimised through options such as deferral, piloting, outsourcing, joint development or sequential investment

(i.e. scaling the investment up or down) as uncertainty is being resolved (Clemons & Weber, 1990; Benaroch, 2002).

Despite the attractiveness of real options analysis for valuing IT investments, empirical implementation presents several challenges. One key challenge stems from strict adherence to financial option pricing techniques by most real options analyses in the literature. While acquiring precise prices for financial options is a necessary condition for market makers to profitably market and sell derivative products to firms (Taudes *et al*., 2000), the purpose of real options analysis is to improve decision-making through flexible management. A survey by Busby & Pitts (1997) found that managers believed current real options tools to be overly complex and not practical for managerial use.

Due to adherence to financial option pricing techniques, most of the extant real options model implementations use stylised data for analysis (e.g. Campbell, 2002; Benaroch *et al*., 2006a). Moreover, some of these analyses focus on the potential value of the option (e.g. Fichman, 2004) and not the actual value which can only be realised after the option is exercised. Furthermore, examining the effect of option exercise decisions requires special treatment of uncertainty and how it is resolved, an issue largely ignored in the literature, even though facilitating flexible management of uncertainty is presumably the basis for real options analysis. In addition, IT-related investments create value in combination with other firm investments and resources (Wade & Hulland, 2004), implying that the value from exercising a real option is likely to be greater than the value of the option on its own, an issue not addressed by extant information systems (IS) research (e.g. Kulatilaka *et al*., 1999; Taudes *et al*., 2000; Benaroch *et al*., 2006a,b; Tiwana *et al*., 2006; 2007).

This study addresses the following questions that have received little attention in the literature:

1 What uncertainty modification factors affect a firm's decision to exercise e-commerce investment real options?
2 What is the effect of a firm's exercise of e-commerce investment real options on performance?

For (1), we empirically examine factors involved in the resolution of internal (endogenous) and external (exogenous) uncertainty and their relationship with real options exercise decisions on e-commerce investments. For (2), we report on an empirical study of the relationship between the exercise of e-commerce investment real options and firm performance.

The next section provides a brief background to the study, with particular emphasis on the dimensions of uncertainty in e-commerce investment projects and the types of real options that may be embedded as a flexible way to deal with uncertainty. Section 3 provides a theoretical overview and hypotheses. Sections 4, 5 and 6 describe the data, analysis and the discussion of results, respectively.

2. BACKGROUND

A firm with an investment opportunity holds a *real option* in that it has the right, but not the obligation, to make the investment at a time of its choosing (i.e. it has the flexibility), taking into

account uncertainty modification (Adner & Levinthal, 2004; Fichman, 2004; Dewan *et al*., 2007). So, a real option confers preferential access to investment opportunity choices by enabling a firm to be better suited for one among several courses of action, decreasing the likelihood of loss while increasing the probability of gain (Bowman & Hurry, 1993; Benaroch & Kauffman, 1999; Benaroch *et al*., 2006b; 2007). Because uncertainty is the key determinant of option-based investing, we discuss its conceptualisation next.

2.1 Dimensions of uncertainty in IT investment projects

Uncertainties are classified as either *exogenous* or *endogenous* (Dixit & Pindyck, 1994; McGrath, 1997; Folta, 1998). Exogenous uncertainty pertains to economic opportunity associated with the investment, due to either economy-wide impacts that are beyond the influence of any firm (pure exogenous uncertainty) or the market viability of an emerging technology whose future potential in the marketplace is uncertain or whose success in the marketplace depends on network effects (McGrath, 1997; Au & Kauffman, 2003). As exogenous uncertainty is largely beyond any single firm's actions, it is predominantly resolved by the passage of time (i.e. 'wait and see') until either economic conditions improve or the technology becomes viable (Folta, 1998; McGrath, 1999; Au & Kauffman, 2003).

Endogenous uncertainty can be conceptualised to consist of *technological endogenous uncertainty* (related to the realisation of the theorised technological promises such as functional feasibility), *organisational endogenous uncertainty* (related to the capacity of the organisation to assimilate the technology) and *inter-organisational endogenous uncertainty* (related to complex inter-firm relationships that influence technological investments). In general, endogenous uncertainty is resolved by firm actions such as organisational learning surrounding the technology (Fichman, 2004) and prior investments in learning (absorptive capacity) that endow the organisation with the ability to successfully assimilate the technology (Cohen & Levinthal, 1990; Fichman, 2004). In the case of *inter-organisational endogenous uncertainty*, joint learning of the collaborating partners may be necessary (Grover & Saeed, 2007).

2.2 Real options in IT investment projects

Studies on IT investments real options draw from Trigeorgis' (1993) real options typology as pertinent to IT investment projects, such as the option to jointly undertake the investment, outsource development, outsource operations or lease (see e.g. Benaroch, 2002; Benaroch *et al*., 2006b; 2007; Tiwana *et al*., 2006, 2007). Our analysis focuses on a subset of three real options that we found to be commonly used in e-commerce investments.[1] These are *stage*, *scale-up* and *joint* e-commerce investment real options. Table 1 summarises these options and the associated investment risks they are intended to mitigate.

The stage real option is a supply-side strategy that entails investing more resources in subsequent phases of an e-commerce system to expand its features. For example, a company

[1]We did an extensive search through LexisNexis to determine the commonly used options in the context of e-commerce investments. We found the *stage*, *scale-up* and *joint development* options to be the most common.

Table 1. E-commerce investment real options

Option	Description	Risks mitigated	Supporting literature
Stage	• Investing more resources in subsequent phases of an e-commerce system to expand features • 'Supply side' moving from limited to full features – '*limited to full*'	Uncertainty in economic opportunities, technical complexity risk and project size/complexity (implementation risks)	Trigeorgis, 1993; Kulatilaka *et al*., 1999; Benaroch, 2002; Lammers & Lucke, 2004; Lee *et al*., 2004; Benaroch *et al*., 2006b; Ranganathan & Brown, 2006; Tiwana *et al*., 2007
Scale-up (Expand)	• Investing more resources in an e-commerce system, to expand it to more users (or larger market) rather than features • 'Demand side' moving from a small to a large group of users or market – '*small to large*'	Low initial demand, and organisational factors (e.g. low management support, user resistance)	
Joint investment	• Leveraging an existing e-commerce relationship/partnership to jointly pursue follow-on investments • 'Resource complementarity perspective' – taking advantage of complementary resources of partners	Knowledge barriers and lack of complementary resources for complete in-house realisation effort	

could roll out its Web site with limited features and then add on full-scale e-commerce functionality in subsequent phases. This option affords the flexibility to implement an investment in phases with the possibility to call off later phases, should conditions prove unfavourable (Benaroch *et al*., 2006b; Tiwana *et al*., 2007). It mitigates uncertainty in economic opportunities and investment implementation risks (such as those arising from project size and complexity).

The scale-up or expand[2] e-commerce investment real option on the other hand is a demand-side strategy which involves investing more resources, rather than features, in an e-commerce system to expand it to more users or to a broader market. For example, a company may make a trial version of its online billing system accessible only to a few customers initially, which then is expanded to the larger or entire base of users or customers later on. Or it may offer e-commerce capability in a given market initially, then subsequently expand to other markets.[3] The expand option mitigates risks such as low initial demand and organisational factors such as user resistance. It enables a firm to capitalise on opportunities through expanded exploitation by scaling up the investment (Kulatilaka *et al*., 1999; Benaroch, 2002).

The joint e-commerce investment real option involves leveraging an existing e-commerce relationship or partnership to jointly pursue follow-on investments. This option is valuable when

[2]In the real options literature, 'scale-up' and 'expand' are used interchangeably to denote the same option.

[3]For example, in May 2000, O A Group Inc launched its online bookstore in Canada, which it expanded to the US market 18 months later after assessing the demand for technical books in the USA.

a firm has a partial set of skills and capabilities required to successfully implement the investment because it enables the firm to leverage complementary resources of other parties, improving the likelihood of success (Lammers & Lucke, 2004; Lee *et al*., 2004).[4]

3. THEORY AND HYPOTHESES

Most e-commerce investments involve a substantial degree of uncertainty; therefore, it is appropriate to use real options analysis to evaluate their business value. To capture the effect of real options exercise decisions, we use the *q*-theory approach to real options analysis suggested by Abel *et al*. (1996), which circumvents the complexity of financial options pricing models. Here, real options valuation can be suitably embedded in the *q*-theory model, making it possible to assess the effects of real options exercise decisions on firm value. In the *q*-theory model, Tobin's *q* is the ratio of the market value of a firm's assets (as measured by the market value of its outstanding stock and debt) to the replacement cost of the firm's assets (Tobin, 1969). Thus, by using a *q*-theory model, the conceptual bridge between strategic action captured by real options and the value of the firm can be strengthened (Bowman & Hurry, 1993). Despite this intuitive appeal, we are unaware of studies that link real options to firm value using Tobin's *q* apart from Bernardo *et al*. (2000) who use Tobin's *q* as a reasonable proxy for the value of the option to diversify and expand into new business segments. We provide a linkage between *q*-theory and real options evaluation later, followed by development of the hypotheses.

3.1 Overview of the link between *q*-theory and real options evaluation

Abel *et al*. (1996) show that the market value of a firm as measured by Tobin's *q* can be decomposed into components consisting of assets already in place and the value of put and call options. Assuming a two-period investment horizon, Abel *et al*. (1996) show that the expected present value of net cash flow accruing to the firm with capital stock K_1 in period 1 can be decomposed as follows:

$$V(K_1) = G(K_1) + \gamma P(K_1) + \gamma C(K_1) \tag{1}$$

where $V(K_1)$ is the total expected present value of cash flows accruing from the firm's capital stock; $G(K_1)$ is the expected present value of returns in periods 1 and 2, without taking into account managerial options that alter the capital stock in period 2; $P(K_1)$ is the value of the put option (i.e. the option to sell capital in period 2); $C(K_1)$ is the value of the call option (i.e. the option to buy capital in period 2); and γ is the discount factor.

As Tobin's *q* is marginal value measure, i.e. $q \equiv V'(K1)$, then differentiating Eqn. 1 with respect to K_1 we obtain

[4]For example, in 2007, Microsoft bolstered its e-commerce solutions partnership with Cactus Commerce – a software service company, with the goal to expand customer benefits from the combined value of Microsoft's expertise in building leading enterprise platform and Cactus' industry-specific solutions and deep knowledge of customer needs, product customisations and service integration.

$$q(K_1) = G'(K_1) + \gamma P'(K_1) + \gamma C'(K_1) \quad (2)$$

where $G'(K_1)$ is the expected present value of the marginal returns to capital evaluated at the first-period capital stock K_1; $P'(K_1)$ is the value of the marginal put option; and $C'(K_1)$ is the value of the marginal call option.

In sum, the aforementioned modelling shows that Tobin's *q* framework captures real options-based decision-making, which facilitates empirical implementation and evaluation of the effects of real options-based investing on firm performance. Later, we demonstrate this through empirical analysis.

3.2 Development of hypotheses

Our research model draws from the standard decision tree framework for real options presented by Adner & Levinthal (2004) depicted in Figure 1. We focus on follow-on investments which represent the exercise of real options already in place. From Figure 1, real options are exercised

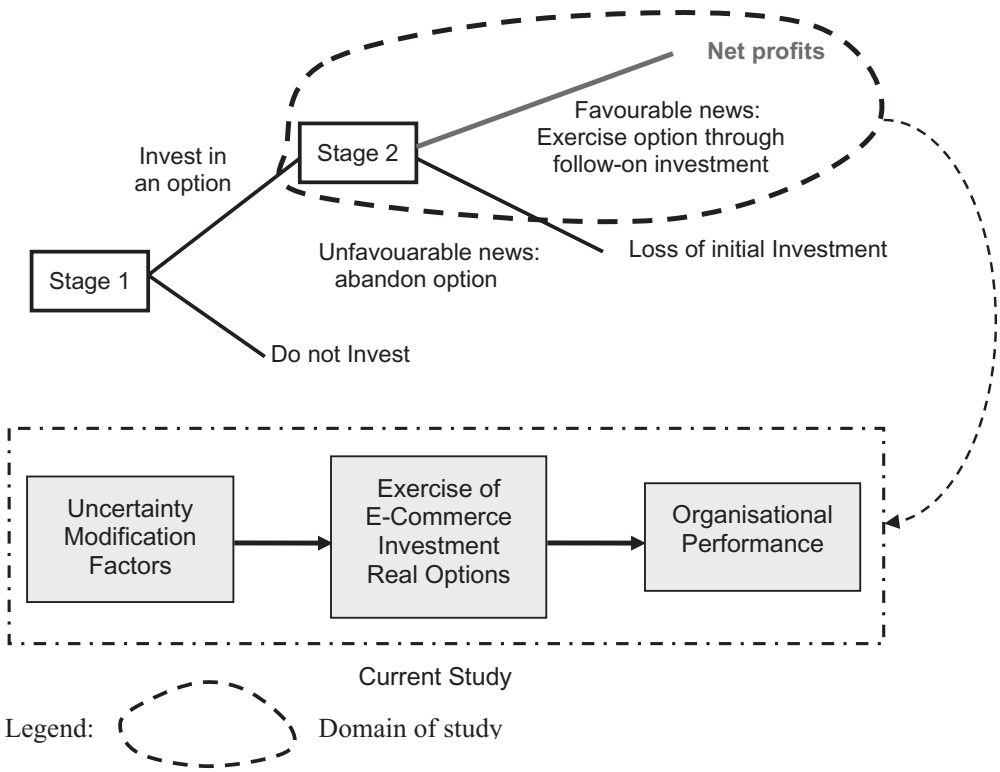

Figure 1. Mapping from the Adner & Levinthal (2004) framework to current study.

through follow-on investments when good news arrives. Follow-on investments are expected to result in cash flow. Following this framework, the suggested model in this study posits that factors that modify uncertainty lead to exercise of e-commerce investment real options, and the exercise of those options is expected to manifest in organisational performance.

3.2.1 Antecedents to real options exercise decisions

Unless an option is exercised, its true value cannot be known; only potential value can be postulated (Fichman, 2004). Therefore, for empirical implementation of the performance effects of an IT investment incorporating real options, those options must be exercised in order for their effect on firm performance to be assessed. Firms benefit from exercising real options embedded in their IT investments when they observe the right signals indicating that uncertainty has been resolved or modified. Using the three e-commerce investment real options in Table 1 and the research model in Figure 1, we present hypotheses on how modification of exogenous and endogenous uncertainty influences a firm's decision to exercise these options and their relationship with firm performance.

3.2.1.1 Exogenous uncertainty modification. The resolution of exogenous uncertainty is indicated by an appropriate signal that is external to the firm. In general, exogenous uncertainty is related to market risks (Benaroch, 2002) and is resolved when appropriate market signals are observed. Bowman & Hurry (1993) suggest that favourable economic opportunity expectations imply an end to the 'wait and see' period. Therefore, a firm can capitalise on this opportunity by making follow-on investments that expand prior investment. Favourable economic opportunity expectations are necessary for a profitable strike; otherwise, the firm may just be escalating commitment to a failing investment (Bowman & Hurry, 1993; Zardkoohi, 2004). To take advantage of such expectations, a firm needs to move swiftly in undertaking the follow-on investment. Firms that lack the necessary skills and capabilities may need to leverage complementary resources of partners to successfully undertake follow-on investment (Dyer & Singh, 1998).

Furthermore, the volatility of the economic opportunity also impacts which e-commerce investments options should be exercised by the firm (Bowman & Hurry, 1993). For example, when there is high volatility in economic opportunity, firms may decide to stage their e-commerce investments by investing sequentially (Herath & Park, 2002). The firm can take advantage of staged capital commitment by making a small initial investment to acquire the right to make follow-on investments, depending on how economic uncertainty unfolds. If economic conditions become favourable, management can decide to proceed with further instalments on the staged capital commitment. Conversely, if economic conditions remain unfavourable, management can decide not to make the follow-on investment (Panayi & Trigeorgis, 1998).

In sum, the preceding arguments imply that favourable economic opportunity expectations motivate managers to exercise the option to *scale up* (*expand*) e-commerce investments by making follow-on investments in order to exploit the opportunity. Firms lacking the necessary skills and capabilities may take advantage of favourable economic opportunity expectations by exercising *joint-investment* option with their partners. Economic opportunity volatility causes

managers to be prudent in their investment decisions by *staging* their e-commerce investments. This is because economic signal volatility implies that considerable inherent risk remains surrounding the economic opportunity. Therefore,

H1a: The more favourable the economic opportunity expectations are, the greater the likelihood that a firm will exercise the scale-up e-commerce investment real option.

H1b: The more favourable the economic opportunity expectations are, the greater the likelihood that a firm will exercise joint e-commerce investment real option.

H2: The greater the volatility of economic opportunity signal, the greater the likelihood that a firm will exercise a stage e-commerce investment real option.

3.2.1.2 Endogenous uncertainty modification. Endogenous uncertainty arises from technology-related and organisational factors. Organisational learning and absorptive capacity are necessary for the resolution of endogenous uncertainty (Cohen & Levinthal, 1990; Ross & Beath, 2002; Fichman, 2004). Formalised organisational learning concerning the adoption and assimilation of technological innovations or new investment opportunities is often carried out through a research and development (R&D) department. The ability of the R&D department to serve as a catalyst in the implementation of an investment initiative is determined by the firm's innovative capabilities and endowments and learning-related endowments (Fichman, 2004). Firms that possess such endowments can undertake the implementation of complex investment projects more economically and with greater probability of success. Learning-related endowments are the stock of a firm's knowledge, skills, routines, incentives and other resources that facilitate effective organisation learning concerning the uncertain investment (Cohen & Levinthal, 1990; Fichman, 2004). Firms lacking in these endowments will experience knowledge barriers, which substantially increase the costs of implementing the investment as well as reduce the likelihood of successful implementation (Attewell, 1992; Fichman, 2004).

Furthermore, a firm's learning-related endowments or learning capabilities influence the decision whether to implement the investment initiative in-house, jointly develop it with a third party or fully outsource it to an external provider. An extensive survey and analysis of IS outsourcing literature by Dibbern *et al*. (2004) shows that among the reasons why firms outsource IS projects is lack of appropriate internal capabilities. Similarly, a study by Nam *et al*. (1996) found that firms with stronger IS-related human assets outsourced less.

We posit that there is an inverted U-shaped curvilinear relationship between the extent of organisational learning and a firm's choice of mode for investment project implementation. Firms with low organisational learning capability will prefer to fully outsource the implementation of their IT-related investments through arm's length market contracting. The implication here is that 'the provider knows best', and implementation details should be left with the provider (Lee *et al*., 2004). Firms with moderate organisational learning capability will tend to prefer joint development as they have a partial set of skills and capabilities and would like to leverage complementary skills and capabilities of an outside provider to ensure successful implementation of the IT-related investment project (Attewell, 1992). Finally, firms with high organisational learning capability may possess the requisite skills and capabilities to

successfully implement the investment project on their own and thus may choose in-house development (Attewell, 1992; Fichman, 2004).

Endogenous uncertainty modification through organisational learning also signals the arrival of an opportunity as internal organisational factors can act as barriers to successful implementation of an investment project if not properly addressed, even though exogenous factors signal an opportunity to exercise the option. Exercising an option to expand an investment after endogenous uncertainty has been resolved is what differentiates option-based investing from escalation of commitment to a failing project (Zardkoohi, 2004). Therefore, the extent of organisational learning increases the likelihood that a firm will exercise the scale-up (expand) e-commerce investment option.

Stage investment option affords the firm the opportunity to learn in stages as it undertakes an investment under uncertainty. This is an effective way of building implementation lead time rather than waiting until uncertainty has been fully modified through learning before making an investment. We argue that firms with high learning endowments may not desire to exercise the stage investment option as they can quickly learn about the situation, resolve uncertainty and undertake the investment as desired. This implies that we expect a negative association between the extent of organisation learning and the exercise of stage e-commerce investment option. While these likely effects are discussed in the real options literature, they have not been formally tested. Therefore, to empirically test these effects, we suggest the following hypotheses:

H3a: There is an inverted U-shaped curvilinear relationship between the extent of organisational learning and the likelihood that a firm will exercise joint e-commerce investment real option.

H3b: The greater the extent of organisational learning, the greater the likelihood that a firm will exercise scale-up e-commerce investment real option.

H3c: The greater the extent of organisational learning, the lesser the likelihood that a firm will exercise stage e-commerce investment real option.

3.2.2 Impact of real options exercise decisions on firm performance

A firm exercises the option to scale up an investment when market conditions turn out to be more favourable than initially expected (Trigeorgis, 1993; Tiwana *et al*., 2006). The option to scale up an investment is related to the concept of 'exploitation' in the organisational learning literature (March, 1991), which is concerned with refinement and expansion of existing opportunities. This option provides managers with the flexibility to increase the resources allocated to an investment to take advantage of the favourable conditions (e.g. a growing customer base, expanding e-commerce transactions, etc.). Given that this option positions a firm to exploit market opportunity, we expect that exercising it should enhance performance. From the organisational learning perspective (March, 1991), compared with returns from exploration that are less certain and remote in time, returns from exploitation are more certain and can be realised immediately. Therefore,

H4a: The exercise of scale-up e-commerce investment real option has a positive effect on firm performance, as measured by Tobin's *q*.

The option to stage e-commerce investment allows for sequential investment in the face of uncertainty. The earlier investments permit the firm to actively explore its technological and organisational ability to realise investment successfully (Benaroch, 2002; Tiwana *et al*., 2006). By actively exploiting the information produced at the end of each investment stage (i.e. about competitors, customers, regulatory bodies and other stakeholders), losses are capped at the cost of the preceding stage, thus limiting a firm's downside exposure under uncertainty (Tiwana *et al*., 2007). In sum, a stage option leads to positive performance effects by lowering a firm's exposure to risk under high uncertainty and by increasing the likelihood of success of the overall initiative due to learning from earlier stages and their contribution to exploitable absorptive capacity in the latter stages (Fichman, 2004). Therefore,

H4b: The exercise of stage e-commerce investment real option has a positive effect on firm performance, as measured by Tobin's *q*.

Exercising the joint-investment option may enable firms to realise successful implementation of the e-commerce investment and ultimately improve their performance as joint investment enables firms to balance the risks and transaction costs of the market with the problems of hierarchical organisation (Hennart, 1993). Total outsourcing is often done through arm's length, loosely coupled, short-term market contracts (Lee *et al*., 2004). There are risks associated with these contracts because even though each party's obligations are specified *ex ante*, contracts are inevitably incomplete due to bounded rationality, vesting the control of unspecified obligations with the provider *ex post* (Klein *et al*., 1978; Grossman & Hart, 1986). Independent in-house development through the hierarchy is also risky because the firm may not have all the requisite skills and capabilities to successfully implement the new investment due to knowledge barriers (Attewell, 1992; Fichman, 2004). Therefore,

H4c: The exercise of joint e-commerce investment real option has a positive effect on firm performance, as measured by Tobin's *q*.

4. DATA AND DESCRIPTIVE STATISTICS

4.1 Measures and data sources

The study integrated three major secondary data sources for construction of the measures and empirical implementation of the study. These are described in Table 2 and are discussed later.

4.1.1 E-commerce announcements

The use of public announcements or events is a valid empirical methodology based on capital markets theory and the efficient-market hypothesis (Fama *et al*., 1969). The hypothesis states that new information about a key corporate event, such as an announcement of e-commerce

Table 2. Measures and data sources

Construct	Measures	Source
Macroeconomic conditions (economic opportunity and its volatility)	• Composite index of leading economic indicators • Volatility of the composite index	Commercial data from the Conference Board (http://www.conference-board.org)
Organisational learning	• R&D expenditures (Cohen & Levinthal, 1990)	Compustat data from Wharton Research Data Services (WRDS) (http://wrds.wharton.upenn.edu)
Exercise of e-commerce investment options	• Expand (scale-up) investment • Stage investment • Joint investment	E-commerce investment announcements from LexisNexis News Wire Services (http://www.lexisnexis.com)
Firm performance	• Tobin's *q* (computed from data)	Compustat data from WRDS (http://wrds.wharton.upenn.edu)
Control variables (Bharadwaj *et al*., 1999; Dewan & Ren, 2007; Miller and Leiblein, 1996)	• Growth potential (MVE/book value) • Capital expenditures • Advertising expenditures • Leverage • Firm size • B2B vs. B2C and Y2K dummy	(B2B vs. B2C dummy and Y2K dummy are coded from e-commerce investment announcements) All other controls are measured using Compustat data from WRDS

investment that can potentially affect a firm's future earnings, is reflected in the current market value of the firm. Although there has been some debate about whether the efficient-market hypothesis holds in capital markets (see e.g. Cochrane, 1991; Schwert, 2003; Boettke, 2010), the theory explains to a very good first approximation how asset prices evolve, taking into account the effect of publicly announced managerial actions (McWilliams & Siegel, 1997; Gompers *et al*., 2003; Schwert, 2003).

Our study follows the established practice in IS research of using data on public announcements of IT-related investments to examine their business value (e.g. Subramani & Walden, 2001; Chatterjee *et al*., 2002; Dehning *et al*., 2003; Ranganathan & Brown, 2006; Dewan & Ren, 2007). We use data on e-commerce investment announcements that reflect real options embedded in the investment to examine the performance effects of exercising these options. We collected the data from a full-text search of e-commerce-related announcements from 1 January 2000 to 31 December 2006 using the online search features of LexisNexis News Wire Services. Other company announcements, such as quarterly earnings announcements, were excluded *a priori*. Using relevant terms, our search yielded 865 announcements over that period. Out of these, we dropped 378 private companies. We then dropped 219 that did not reflect follow-on investments, and we dropped 96 more because the announcing companies did not have listing on the stock markets that encompassed the period of our study. The final 172 announcements consisted of 45, 52 and 75 for stage, expand and joint-investment options, respectively. The sample comprised mainly of medium to large public companies with sales ranging from around $30 million to over $5 billion. We normalised (i.e. expressed as a ratio to sales) continuous variables in our analysis to

account for variation in firm size. While several industries were represented, retail and financial sectors were more prominent.

4.1.2 Determination and coding of real options

We took careful steps to ensure that the e-commerce announcements represented the exercise of real options. First, an announcement had to reflect a follow-on investment, implying that a real option was being exercised (see Sample Announcements in the Appendix). Second, we examined the texts of the announcements carefully, looking for specific identifying words or phrases for the type of real options examined in this study. The full press release served as the coding frame, consistent with earlier studies of IT announcements (e.g. Chatterjee *et al*., 2002; Dehning *et al*., 2003; Ranganathan & Brown, 2006). Press releases were coded as a single type of e-commerce real option being exercised, based on our interpretation of most representative manner in which the follow-on investment is undertaken (i.e. either stage, expand or joint investment).

We developed a set of coding rules (see Appendix) using data from six announcements not included in the study. First, three of these announcements were used to develop an initial set of coding rules. Thereafter, two coders independently went through the other three announcements and assigned codes based on what they thought was the most representative e-commerce investment option being exercised. After this, the coders met to assess agreement in code assignments. During the meeting, any disagreements in code assignments were discussed and resolved, and the coding scheme was updated before coding the announcements used in the study.

With the finalised coding scheme, the two coders independently went through the announcements and assigned codes based on what they thought was the most representative e-commerce investment option being exercised. For scale-up e-commerce investment option, the coders examined the texts of the announcements, looking for words such as 'scale-up', 'expand', 'raise', extend, increase, etc. Similarly, the coders examined the texts of the announcements once again to determine the stage e-commerce investment option, paying attention to words or phrases such as 'stage', 'investment in phases', 'subsequent phases', 'staged investment', etc. Finally, the coders examined the texts of the announcements once again to determine the joint e-commerce investment option, looking for the phrases such as 'joint development,' 'joint investment', 'joint project', 'in partnership with,' 'strategic partnership', etc. After completing the coding, we assessed inter-rater reliabilities using Cohen's Kappa; our inter-rater coefficient of 0.83 shows substantial agreement (Landis & Koch, 1977).

4.1.3 Dependent variable

Tobin's *q*, measured as the ratio of the market value of a firm's assets (equity and debt) to their replacement cost (Tobin, 1969), is the dependent variable used in this study. It captures intangible assets not captured by accounting measures of performance, such as return on assets, ratio of cost of goods to sales, etc. (Lane & Jacobsen, 1995; Lowenstein, 1996;

Bharadwaj *et al*., 1999). As the value of real options is influenced by intangible managerial discretion and flexibility (about when to hold, exercise or abandon an option), we find it appropriate to use Tobin's *q* in our analysis instead of the accounting measures of performance. Furthermore, our analysis is based on announcements, which are forward-looking statements. These announcements reflect intended actions or actions that are underway, whose outcomes are in the future. Tobin's *q* is an appropriate measure to capture future performance effects of such actions. In this study, we use Chung & Pruitt's (1994) method to measure Tobin's *q* because it is simple and requires publicly available data for implementation. This approach has previously been used in IS research (e.g. Bharadwaj *et al*., 1999). Tobin's *q* ratio is computed as follows:

$$\text{Tobin's } q = \frac{(MVE + PS + DEBT)}{TA} \tag{3}$$

where *MVE* is the market value of equity, computed as (closing price of share at the end of the financial year $\times$ number of common shares outstanding); *PS* is the liquidating value of the firm's outstanding preferred stock; *DEBT* is computed as (current liabilities $-$ current assets) $+$ (book value of inventories $+$ long-term debt); and *TA* is the book value of total assets.

4.2 Resolution of exogenous uncertainty

In macroeconomic terms, aggregate economic indicators are used to provide a broad picture of the economic situation of a given economy and predict the manner in which this situation will unfold in the near future (Frumkin, 2000). In general, three kinds of economic indicators are used: *leading* indicators (what the economic situation is going to be in the near future), *coincident* indicators (what the economic situation is now) and *lagging* indicators (what the economic situation has been in the recent past). The composite indexes are the key elements in an analytic system designed to signal peaks and troughs in the business cycle as they are constructed to summarise and reveal common turning point patterns in economic data in a clearer and more convincing manner than any individual component (The Conference Board, 2010). The leading indicators index, in particular, is instrumental in forecasting future events because it includes indicators signalling forthcoming economic opportunities (e.g. index of consumer expectations, manufacturers' new orders and housing starts). In our analysis, the resolution of exogenous uncertainty pertains to the overall economic situation, which we capture using the *leading indicators index*. Our choice of this index is consistent with forward-looking statements in the announcements[5] and, from the theoretical standpoint, the assumption of forward-looking rational economic agents.[6] The Conference Board maintains data on

[5]For instance, an announcement made by Entrade and Associates in March 2000 had the following statements: 'Statements contained in this press release, which are not historical facts, are forward-looking statements. Such forward-looking statements are necessary estimates reflecting the best judgement of the party making the statement based on available information.'

[6]In macroeconomic theory, it is necessary to model how economic agents form their expectations about future variables. A major problem is that such expectations are generally unobservable, necessitating making assumptions about their

6-months ahead forecast of the expected state of the US economy and its diffusion (volatility) over a 6-month span. Using the monthly data, we computed the average index and its volatility on a quarterly basis for the quarter preceding the e-commerce announcement.

4.3 Endogenous uncertainty modification

The resolution of endogenous uncertainty is influenced by the firm's absorptive capacity (i.e. ability to assimilate and exploit external knowledge) and investments in learning. In applied work, R&D expenditures are often used to indicate the extent of an organisation's investment in learning about investment opportunities. Cohen & Levinthal (1990) use R&D expenditures as a proxy for absorptive capacity and find empirical support for the effect of R&D expenditures in both generating innovation and facilitating learning. Moreover, they find that a higher level of R&D is necessary to build absorptive capacity when technological opportunity is greater, i.e. greater amounts of external information. Our study spans a period of great technological opportunity for e-commerce investments; we use R&D expenditures to measure the extent of organisational learning.

In the USA, financial reporting of corporate R&D expenditures requires corporations to immediately expense their R&D expenditures instead of capitalising them (Wasley & Linsmeier, 1992; Kothari *et al*., 2002). In their empirical study, Kothari *et al*. (2002) find that expensed R&D influences earnings variability more so than capitalised R&D, lending support to the requirement to immediately expense R&D expenditures in financial reporting. Thus, we use annual R&D expenditures instead of capitalised R&D expenditures in our analysis. Furthermore, previous R&D studies find that R&D expenditures have a lag effect on performance (Lach & Rob, 1996; Goel & Ram, 2001). Due to the difficulty of treating distributed lag structures in applied work, the Koyck transformation – which takes into account only previous period's R&D expenditures – is often used in statistical analysis (Ravenscraft & Scherer, 1982). Thus, we use R&D expenditures of the year preceding the announcement as a proxy for the extent of organisational learning for resolution of endogenous uncertainty and, hence, as a trigger of options exercise decisions. We take the ratio of R&D expenses to sales to ensure a comparable value across firms.

4.4 Control variables

While the focus was on developing a parsimonious model consistent with our theoretical framework, it is important to include several control variables in empirical analysis to enhance the validity of our findings. Previous IT value studies have used numerous firm-specific and industry variables as controls in empirical analysis (e.g. Bharadwaj *et al*., 1999; Dewan *et al*., 2007). Table 3 presents pertinent control variables used in this study.

formation. Several assumptions about how economic agents form expectations have been introduced in the literature, including naïve, adaptive and rational (Muth, 1961; Nerlove, 1975; Sheffrin, 1996). Rational expectations hypothesis, which assumes that expectations are optimal predictions of future outcomes given all the available information, has become widely accepted in the literature. Thus, we use rational expectations assumption in our analysis.

Table 3. Control variables

Variable	Rationale	Literature support
Lagged *q* measure (preceding year value)	Firm-specific factors affecting performance tend to persist across time periods	Bharadwaj *et al*., 1999
Growth potential	Growth prospects vary across firms due to industry positioning	Porter, 1980
Firm size	Size influences firm resources and capabilities	Bharadwaj *et al*., 1999
Capital expenditure	Captures capital endowments	Kothari *et al*., 2002; Dewan *et al*., 2007
Leverage	Debt overhang reduces investment incentive, which ultimately affects firm performance	Lang *et al*., 1996; Ahn *et al*., 2006
Advertising expenditure	A firm's advertising creates intangible market-based assets, which strengthens performance	Srivastava *et al*., 1998; Rao *et al*., 2004
B2B dummy	The risks associated with B2B investments tend to differ from those of B2C investments	Subramani & Walden, 2001; Dewan & Ren, 2007
Y2K dummy	The dot-com bubble burst in 2000, affecting firm valuations	Inferred from observing data

5. ANALYSIS AND RESULTS

5.1 Statistical analyses

To examine how the resolution of uncertainty influences options exercise decisions, we use logistic regression analysis. Classical regression analysis is based upon the ordinary least squares procedure; it makes assumptions of normally distributed and homoscedastic errors, which are violated when the dependent variable is dichotomous (Cohen *et al*., 2003). Logistic regression relaxes these assumptions and applies the more efficient maximum likelihood estimation procedure using the natural log to estimate the odds of the dependent event occurring or not (Peng & So, 2002; Cohen *et al*., 2003). In our analysis, we tested our hypotheses (H1–H3) through the following logistic regression models for the effect of the resolution of uncertainty on real options exercise decisions:

$$\begin{aligned} Ln[odds(\textit{scale-up option})_t] = {} & \alpha_0 + \alpha_1 Size_t + \alpha_2 Growth_t + \alpha_3 Capital_t + \alpha_4 Leverage_t \\ & + \alpha_5 Ad_t + \alpha_6 B2B_t + \alpha_7 Y2K + \alpha_8 R\&D_t \\ & + \alpha_9 EconOpport_t + \varepsilon \end{aligned} \tag{4}$$

$$\begin{aligned} Ln[odds(\textit{stage option})_t] = {} & \beta_0 + \beta_1 Size_t + \beta_2 Growth_t + \beta_3 Capital_t + \beta_4 Leverage_t \\ & + \beta_5 Ad_t + \beta_6 B2B_t + \beta_7 Y2K + \beta_8 R\&D_t + \beta_9 Volatility_t + \varepsilon \end{aligned} \tag{5}$$

$$\begin{aligned} Ln[odds(\textit{joint devt option})_t] = {} & \gamma_0 + \gamma_1 Size_t + \gamma_2 Growth_t + \gamma_3 Capital_t + \gamma_4 Leverage_t \\ & + \gamma_5 Ad_t + \gamma_6 B2B_t + \gamma_7 Y2K + \gamma_8 R\&D_t + \gamma_9 R\&D^2{}_t + \varepsilon \end{aligned} \tag{6}$$

Furthermore, we specify the following hierarchical regression model to test hypotheses (H4) for the effect of real options exercise decisions on firm performance. Hierarchical regression

allows for step-wise introduction of a set of variables into the model (Cohen *et al*., 2003), enabling us to isolate the effect of control variables and those attributable to real options exercise decisions.

$$Q_t = \phi_0 + \phi_1 Q_{t-1} + \phi_2 Growth_t + \phi_3 Size_t + \phi_4 R\&D_t + \phi_5 Capital_t + \phi_6 Ad_t + \phi_7 Leverage_t + \phi_8 Y2K + \phi_9 B2B_t + \phi_{10} Scale\text{-}up_t + \phi_{11} Stage_t + \phi_{12} JointDev_t + \varepsilon \quad (7)$$

where Q_t is Tobin's *q* ratio for firm in year *t*; Q_{t-1} is Tobin's *q* ratio for firm in year $t-1$; $Size_t$ is the firm size (log (number of employees)) in year *t*; $Growth_t$ is the firm's growth potential (MVE/Book value) in year *t*; $Capital_t$ is the ratio of firm's capital expenditure to sales in year *t*; $Leverage_t$ is the ratio of firm's long-term debt to book value of equity in year *t*; Ad_t is the ratio of firm's advertising expenditure to sales in year *t*; $B2B_t$ (business-to-business) is the dummy variable for type of announcement (1 = B2B; 0 = B2C (business-to-consumer)) in year *t*; *Y2K* is the dummy variable for the year 2000 (1 = 2000; 0 = otherwise); $R\&D_t$ is the ratio of firm's R&D expenditure to sales in year *t*; $EconOpport_t$ is the 6-month leading indicators index for the US economy in period *t*; $Volatility_t$ is the diffusion of the leading indicators index in period *t*; $R\&D^2_t$ is the square of the ratio of firm's R&D expenditure to sales in year *t*; $Scale\text{-}up_t$ is the announcement of the option to scale up e-commerce investment in year *t*; $Stage_t$ is the announcement of the option to stage e-commerce investment in year *t*; and $JointDev_t$ is the announcement of the option to jointly develop e-commerce project in year *t*.

5.2 Results

5.2.1 Antecedents to real options exercise decisions

5.2.1.1 Omnibus test of model coefficients. The likelihood ratio test of the overall model fit (i.e. model chi-square test) tests the significance of the difference between the log-likelihood for the research model and that for the null model (i.e. model with constant only). In all three logistic regression models fitted, the likelihood ratio test is significant ($\chi^2_{,9} = 33.30$, $p < 0.01$) for the *scale-up* (*expand*) option model; ($\chi^2_{,9} = 19.248$, $p < 0.05$) for the *stage* option model; and ($\chi^2_{,9} = 42.957$, $p < 0.01$) for the *joint development* option model (Tables 4–6). These findings are further supported by the Cox and Snell and Nagelkerke pseudo R^2 statistics, which are also significant at the 0.05 level.[7] Thus, in each model, explanatory variables as a whole lead to an improvement in fit compared with the null model.

5.2.1.2 Individual model coefficients. The Wald statistic[8] tests the significance of individual logistic regression coefficients for each independent variable. All the hypothesised relationships except Hypothesis 3c are significant based on the Wald test. In Tables 4–6, the odds ratio, or exp(B) for a given independent variable, represents the factor by which the odds of an

[7]The Cox and Snell's R^2 and Nagelkerke's R^2 are pseudo-R^2 measures comparable to the conventional R-squared and provide a reasonable approximation for goodness-fit of the model (Cohen *et al*., 2003).
[8]Wald = $[B/SE(B)]^2$. In other words, Wald $\equiv t^2$.

Table 4. Logistic regression results for the effect of uncertainty modification on the exercise of scale-up e-commerce investment option

Variable	B	SE	Wald	*p*-value	Odds ratio (exp(B)])
Constant	–3.515**	1.079	10.616	0.001	0.030
Firm size	–0.018	0.096	0.035	0.852	0.982
Growth potential	0.087*	0.042	4.175	0.041	1.091
Capital expenditure	0.362	0.367	0.972	0.324	1.437
Leverage	0.076	0.145	0.276	0.599	1.079
Ad expenditure	–1.352	1.930	0.491	0.483	0.259
B2B dummy	1.833**	0.671	7.463	0.006	6.253
Y2K dummy	0.540	0.387	1.948	0.163	1.797
R&D expenditure	2.331*	1.008	5.350	0.021	10.285
Economic opportunity	0.174**	0.065	7.102	0.008	1.190

B, estimated coefficient; SE, standard error.

*$p < 0.05$.

**$p < 0.01$.

Model fit: $\chi^2_{,9} = 33.30$; $p < 0.01$; Cox & Snell $R^2 = 0.176$; Nagelkerke $R^2 = 0.241$; $N = 172$.

Table 5. Logistic regression results for the effect of economic opportunity volatility on the exercise of stage e-commerce investment option

Variable	B	SE	Wald	*p*-value	Odds ratio (exp(B))
Constant	–1.848*	0.991	3.475	0.062	0.158
Firm size	–0.059	0.095	0.386	0.534	0.943
Growth potential	0.047	0.041	1.341	0.247	1.048
Capital expenditure	0.468	0.393	1.417	0.234	1.597
Leverage	0.186	0.143	1.691	0.193	1.204
Ad expenditure	–0.377	1.163	0.105	0.746	0.686
B2B dummy	1.150**	0.575	3.992	0.046	3.157
Y2K dummy	0.198	0.438	0.204	0.652	1.219
R&D expenditure	–1.672	1.141	2.145	0.143	0.188
Economic opportunity volatility	2.857**	1.214	5.539	0.019	17.406

B, estimated coefficient; SE, standard error.

*$p < 0.10$.

**$p < 0.05$.

Model fit: $\chi^2_{,9} = 19.248$; $p < 0.05$; Cox & Snell $R^2 = 0.106$; Nagelkerke $R^2 = 0.149$; $N = 172$.

option being exercised change for a one-unit change in the independent variable. The independent variable may increase the odds a given option is exercised (when exp(B) > 1.0), have no effect (Exp(B) = 1.0) or decreases odds a given option is exercised (exp(B) < 1.0).

From Table 4, both of the hypothesised relationships are supported. Economic opportunity expectations (B = 0.174; Wald = 7.102; $p < 0.01$) is positively related to log (odds *scale-up option* exercised), supporting Hypothesis 1a. The corresponding odds ratio implies that for a

Table 6. Logistic regression results for the effect of extent of organisational learning on the exercise of joint e-commerce investment real option

Variable	B	SE	Wald	*p*-value	Odds ratio (exp(B))
Constant	–0.685	0.943	0.528	0.467	0.504
Firm size	0.241**	0.096	6.337	0.012	1.273
Growth potential	0.030	0.046	0.407	0.523	1.030
Capital expenditure	–0.143	0.396	0.130	0.718	0.867
Leverage	–0.095	0.135	0.497	0.481	0.910
Ad expenditure	–0.445**	0.203	4.786	0.029	0.641
B2B dummy	–0.908*	0.505	3.238	0.072	0.403
Y2K dummy	0.169	0.440	0.147	0.701	1.184
Economic opportunity	0.276***	0.078	12.535	0.000	1.318
R&D expenditure	2.125***	0.766	7.669	0.006	8.373
(R&D expenditure)^2	–3.944**	2.234	3.115	0.048	0.019

B, estimated coefficient; SE, standard error.

*$p < 0.10$.

**$p < 0.05$.

***$p < 0.01$.

Model fit: $\chi^2_{,9} = 42.957$; $p < 0.01$; Cox & Snell $R^2 = 0.222$; Nagelkerke $R^2 = 0.296$; $N = 172$.

one-unit increase in the economic opportunity expectations index, the odds that the firm will exercise the expand option increase by 1.19. Similarly, R&D expenditure (which represents investments in organisational learning to resolve endogenous uncertainty), with (B = 2.331; Wald = 5.350; $p < 0.05$) is positively related to log (odds *scale-up option* exercised), supporting Hypothesis 3b. The odds ratio of 10.285 implies that a one-unit increase in the R&D expenditure to sales ratio increases the likelihood that a firm will exercise the expand e-commerce investment option by about 10 times.

From Table 5, economic signal volatility (B = 2.857; Wald = 5.539; $p < 0.05$) is positively related to log (odds *stage option* exercised), supporting Hypothesis 2. The corresponding odds ratio of 17.406 implies that a one-unit increase in the volatility in the economic signal index increases the likelihood that a firm will exercise the *stage* e-commerce investment option by about 17 times. The estimated coefficient for R&D expenditure (measure of extent of organisational learning), while of the hypothesised sign, is not statistically significant. Therefore, Hypothesis 3c is not supported.

From Table 6, *joint option* exercised, the estimated coefficient for R&D expenditure to sales ratio of 2.125 (Wald = 7.669; $p < 0.01$) and that of the square term of –3.944 (Wald = 3.115 $p < 0.05$) imply a concave function (i.e. inverted U-shaped function). Therefore, Hypothesis 3a is supported. Similarly, the estimated coefficient for economic opportunity expectations index of 0.276 (Wald = 12.535; $p < 0.01$) supports Hypothesis 1b.[9]

[9]Among control variables, for the *scale-up option*, only growth potential (B = 0.087; Wald = 4.175; $p < 0.05$) and B2B dummy (B = 1.833; Wald = 7.463; $p < 0.01$) are positively related to log (odds *scale-up option* exercised). These findings are plausible since firms will most likely scale-up their e-commerce investment to take advantage of growth potential. The

5.2.2 Impact of real options exercise decisions on firm performance

Hierarchical regression results for the effect of real options exercise decisions on firm performance (Tobin's *q*) are shown in Table 7. Step 1 results are for the model with only control variables. Omnibus model test indicates that the model is statistically significant ($F = 11.281$, $p < 0.001$), and control variables explain about 35.6% of the variance in firm value. Statistically significant control variables in the model include lagged *q* measure ($\beta = 0.272$, $p < 0.01$), growth potential ($\beta = 0.410$, $p < 0.01$) and leverage ($\beta = -0.142$, $p < 0.05$). The lagged dependent variable controls for path dependencies in firm value because investment is subject to adjustment costs, and as a result, a firm partially adjusts its investment to the desired long-run value (Hayashi, 1982). Path dependency implies that current firm performance is positively related to past

Table 7. OLS results for the effect of options exercise on firm performance

	Step 1: control variables		Step 2: full model	
	β	T stat	β	T stat
Constant	0.952	0.945	0.540	0.536
Q_{t-1}	0.272***	3.596	0.255***	3.467
Growth potential	0.410***	5.390	0.430***	5.736
Firm size	–0.001	–0.015	–0.033	–0.512
Capital expenditure	–0.039	–0.605	–0.030	–0.470
Advertising expenditure	–0.070	–1.020	–0.045	–0.659
Leverage	–0.142**	–2.167	–0.130**	–2.036
Y2K dummy	–0.029	–0.473	–0.015	–0.241
B2B dummy	–0.047	–0.712	–0.011	167
Exercise of scale-up option			0.172*	1.872
Exercise of stage option			0.030	0.467
Exercise of joint development option			0.208***	2.603
R^2	0.356		0.404	
Adjusted R^2	0.325		0.363	
F value	11.281†		9.856†	
p-level	0.000		0.000	
ΔR^2			0.048**	
Sample size	172		172	

*$p < 0.10$.
**$p < 0.05$.
***$p < 0.01$.
†$p < 0.001$.

only control variable significant in *stage option* model is the B2B dummy (B = 1.150; Wald = 3.992; $p < 0.05$), perhaps reflecting the complexity of B2B initiatives. For *joint development option*, significant control variables include firm size (B = 0.241; Wald = 6.337; $p < 0.05$) and the ratio of advertising expenditures to sales (B = –0.445; Wald = 4.786; $p < 0.05$). Larger firms often have superior human capital and other resources to enable them to exercise joint investments with partners.

performance. As expected, growth potential is positively related to Tobin's *q*. As the study uses panel data, growth potential implicitly controls for growth prospects related to industry positioning. As the estimate for the Y2K dummy is not statistically significant, the dot-com burst that happened in 2000 does not influence the pattern of the results.

In step 2 of the hierarchical regression analysis, the full model incorporating real options measures was estimated. The change in R^2 of 4.8% is significant ($F = 4.253$, $p < 0.01$), implying that real options measures add explanatory power to the model. The results support Hypothesis 4c pertaining to the exercise of the joint development option ($\beta = 0.208$, $p < 0.01$), and weakly support Hypothesis 4a concerning the exercise of the scale-up (expand) option ($\beta = 0.172$, $p < 0.10$). However, Hypothesis 4b pertaining to the performance effects of the exercise of stage e-commerce investment option is not supported ($\beta = 0.030$, $p = 0.467$). These findings are consistent with those of Tiwana *et al*. (2006).

6. DISCUSSION

Several studies have examined the usefulness of real options analysis in evaluating the business value of IT investments. However, the lack of studies examining factors affecting real options exercise decisions is rather surprising given that the importance of learning actions like exploration, experimentation and R&D was recognised early in the economic and management literatures (e.g. Roberts & Weitzman, 1981; March, 1991). Furthermore, prior implementations of real options models have been limited to stylised analyses, simulation and case studies due to the complexity of the models used. Here, we used a simple generalised model that embeds real options in firm valuation using *q*-theory. Our empirical findings provide insight into how the resolution of uncertainty impacts real options exercise decisions and performance, in the context of e-commerce investments.

6.1 Antecedents to real options exercise decisions

Our results show that the resolution of both exogenous and endogenous uncertainty increases the odds that a firm will exercise scale-up (expand) e-commerce investment option. However, the resolution of endogenous uncertainty has higher impact on the decision to exercise scale-up e-commerce investment option. This could be due to the fact that while the resolution of exogenous uncertainty is beyond a firm's control, the resolution of endogenous uncertainty is influenced by firm actions. Therefore, firms that actively invest in organisational learning and that undertake business experiments (Ross & Beath, 2002; Fichman, 2004) have a higher ability to resolve endogenous uncertainty and are more likely to detect opportunities to expand their e-commerce investments. Furthermore, focused business experiments endow a firm with exploitable absorptive capacity (Fichman, 2004), which enables it to exploit subsequent investment opportunities.

Our empirical findings imply that a firm's decision to exercise the *stage* e-commerce investment option is influenced by economic opportunity volatility, which is related to the resolution

of exogenous uncertainty. While the often recommended strategy regarding exogenous uncertainty is to 'wait and see' (McGrath *et al*., 2004), this is not adequate when the signal indicating the resolution of exogenous uncertainty is noisy. As is always the case in the real world, managers have to make decisions and take actions with imperfect information by exercising the *stage* option.

The results from this study show that economic opportunity expectations have an effect on the firm's decision to exercise joint e-commerce investment option. Because the competitive advantage derived from IT-related investments is often short-lived (Mata *et al*., 1995; Wade & Hulland, 2004), firms need to act swiftly to exploit the opportunity and capitalise on first-mover advantages. They can do so by leveraging the complementary resources of partners through the exercise of joint e-commerce development option. Furthermore, the results from this study indicate an inverted U-shaped curvilinear relationship between a firm's investments in learning and the exercise of *joint development option*. This is consistent with the reasoning that firms exercise joint-investment option to exploit complementary resources of partners, as well as balance the risks associated with full in-house implementation of total outsourcing.

6.2 Options exercise decisions and firm performance

The empirical findings show that exercise of the joint e-commerce investment real option is positively related to firm performance. Thus, joint investment is an effective way to mitigate risks associated with e-commerce investment implementation. This result is consistent with findings from an IT outsourcing study by Lee *et al*. (2004), who found that embedded (network) strategies (similar to the joint-investment option in the current study) outperform arm's length (market) and independent (hierarchy) strategies on technology catalysis (facilitated assimilation of the technology due to resource complementarity and flexibility). Such investment options give a firm access to complementary resources of partners, which leads to successful implementation. The relationship between the exercise of the scale-up e-commerce investment option and firm performance is weakly supported, while there is no significant relationship between the exercise of the stage option and firm performance. These findings are somewhat consistent with those of Tiwana *et al*. (2006) who found that the stage option is of little importance in shaping managerial perceptions of option value. They found the scale option to be slightly more important than the stage option. These results imply that options that decrease the severity of loss may be more important than those that decrease the probability of loss. For stage option, exercising investment in subsequent stages is still risky because the future is uncertain.

6.3 Limitations of the study

This work has some limitations. First, while we employed extra care to ensure that the text of the announcement implied the exercise of a real option, this may not be apparent from just examining the text of the announcement. For example, it is difficult to differentiate between a true exercise of the scale-up option and escalation of commitment. This is because it is often

tempting for managers to escalate commitment to investment projects, especially if not doing so affects their reputation or if they have high stakes in the investment (Zardkoohi, 2004). Future work could mitigate this limitation by implementing a field survey. Second, while we focused on real options that we found to be common in the e-commerce domain, future work could use this methodology to examine other real options. Third, we did not explicitly treat option interactions in this work (Trigeorgis, 1993). Future work could also examine multiple interacting options and their effect on performance. Finally, we considered only a limited set of factors that influence a firm's real choices. Future work could consider other factors, such as standards formation process and how it affects the decision to exercise investment options associated with an emerging technology.

6.4 Implications for research and practice

Our study has several implications for research and practice. First, as the management of uncertainty is the main reason for using real options, our study calls upon researchers to improve upon the conceptualisation of various types of uncertainty. Second, while prior studies are concerned with the determination of the value of a specific option (as in the case of financial options), our study echoes Bettis' (1994) challenge for scholars to pay more attention to the organisational process in the creation and use of real options. As we have demonstrated in this study, researchers need to broaden their view on real options valuation in order to create continuity between real options research and IT value research. This may help scholars to come up with simpler real options valuation approaches that will be embraced by practitioners, which could improve practitioner's ability to profit from the use of real options to assess the pay-off of IT investments. Third, our study contributes to the notion of joint value creation by leveraging the complementary resources of partners (Dyer & Singh, 1998). Lastly, our study provides empirical support for the use of Tobin's *q* in real options valuation. By doing so, we take the initial steps in empirically validating the performance effects of real options exercise decisions based on *q*-theory. Given that Tobin's *q* is a simpler approximation to the usually complex stochastic differential equations used in financial options evaluation, the linkage between real options and Tobin's *q* offers a promising avenue for future empirical research on real options outcomes.

For managers, our results imply that simply waiting without investment in active learning *does not* create significant value from real options. The key differentiator is how they resolve endogenous uncertainty as this endows them with the ability to successfully undertake the IT investment and exploit the economic opportunity implied by the resolution of exogenous uncertainty. Therefore, managers need to invest in active learning in the form of research and development (i.e. perform business experiments) if they expect to realise benefits from the use of real options logic. In addition to their investments in learning, benefiting from real options investment logic requires firms to particularly pay more attention to nurturing partnerships and leverage the complementary assets of partners. Furthermore, our results seem to imply that different options should be used to manage situations involving certainty of loss on one hand and severity of loss on the other hand. Stage options seem to be suited to the management of

certainty of loss (using volatility of economic opportunity as a proxy), while scale-up and joint-investment options appear suited to the management of severity of loss (using economic opportunity as a proxy). Perhaps, managers need to maintain a portfolio of options to manage the two dimensions of risk simultaneously. However, given that exercise of stage option did not have significant effect on performance, options designed to manage severity of loss may be of more practical significance. Thus, it is important for managers to make the right choices when using options-based investing logic for risk management.

7. CONCLUSION

This study examined the effect of the resolution of uncertainty on real options exercise decisions with respect to three e-commerce investment options: *scale-up*, *stage* and *joint investment*, and the relationship between exercise of these options and firm performance. The findings underscore the significance of differentiating between exogenous and endogenous uncertainty. Unlike other real option studies, our results imply that to exercise options that create value, firms cannot afford to take only the 'wait and see' stance; they have to invest in learning and perform business experiments to resolve endogenous uncertainty. This is of paramount importance as the resolution of endogenous uncertainty endows the firm with the ability to successfully undertake the investment and exploit the economic opportunity implied by the resolution of exogenous uncertainty. Furthermore, our results suggest that different options should be used to manage situations involving certainty of loss on one hand and severity of loss on the other hand.

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APPENDIX: CODING SCHEME AND SAMPLE EXCERPTS FROM ANNOUNCEMENTS

Coding scheme

We searched the Lexis/Nexis database (which incorporates Business Wire and PR Newswire databases) to identify announcements of e-commerce investments over the period 2000–2006. We considered only press releases that explicitly stated the firm as the source. Earnings statements released to the press were not coded, even statements about e-commerce, since the motivation was to address the earnings rather than e-commerce investment. Furthermore, we made sure that the e-commerce announcement was a follow-on investment that reflects exercise of investment options created through prior investments. Specifically, we applied the following coding rules:

1 Do not code general statements about e-commerce investments, must report a specific follow-on e-commerce investment (look for words such as: 'extends', 'expands', 'leverages existing or prior investments', 'builds upon', 'add', etc.).
2 Do not code earnings statements.
3 Use the following words/phrases to code *stage* option: 'stage', 'investment in phases', 'subsequent phases', 'staged investment'; pertaining to *features* of system.
4 Use the following words/phrases to code *expand* (*scale-up*) option: 'scale-up', 'expand', 'broaden', 'extend', 'increase'; pertaining to *users* or *market*.
5 Use the following words/phrases to code *joint e-commerce investment* option: 'joint development', 'joint investment', 'joint project', 'in partnership with', 'strategic partnership', 'collaborate', 'collaboration', 'alliance'.
6 Based on rules 3–5, assign one code to the entire newswire (announcement), where the appropriate code is the dominant manner in which the e-commerce investment is implemented, and/or its intent.

7 If there is not enough detail to determine if an exercise of e-commerce investment option (i.e. it is not a follow-on investment and the above key words do not appear), no code is assigned.

Sample announcements

Option	Sample Announcement[1]
Scale-up (Expand)	HEADLINE: ComputerLiteracy.com Expands Successful Business-to-Business E-Commerce Model Into New Markets DATELINE: SUNNYVALE, Calif., March 15, 2000 BODY: (abbreviated) In a move which extends its successful business-to-business e-commerce model beyond the information technology market, ComputerLiteracy.com (Nasdaq : CMPL), today announced that it has expanded its reach into additional vertical markets to deliver the most comprehensive selection of professional books to organisations in the engineering, science, mathematics and financial services industries. The company's expansion represents a significant growth in its targeted markets within a business-to-business e-commerce sector.
Stage	HEADLINE: Unigraphics Solutions Announces in-KEY – a New Family of Collaborative Software and Services for e-Commerce DATELINE: ST. LOUIS, March 2, 2000 BODY: (abbreviated) Unigraphics Solutions Inc. (NYSE : UGS) today announces in-KEY – a major extension to its already rich product and services portfolio. in-KEY is a family of business transformation solutions that address the manufacturing industry's need to exploit the B2C (business-to-consumer) and B2B (business-to-business) e-Commerce opportunities provided by the internet. Major manufacturing companies are using our solutions to capture their product definition and knowledge. in-KEY will unlock the value that resides in this data and allow our customers to fully leverage their intellectual capital across the extended enterprise. While in-KEY encompasses the entire enterprise with several solution offerings planned to address the eight key processes of manufacturing organisations, the company is rolling out first three in-KEY solutions, with rest to follow in subsequent phases. Custom versions of these solutions have been proven at customer sites.
Joint Development	HEADLINE: JDA Software Announces Strategic E-Commerce Initiative with IBM To Deliver Low Risk Solution for E-tailers DATELINE: SCOTTSDALE, Ariz., Feb. 10, 2000 BODY: Solution Combines JDA, IBM Products and Implementation Services JDA(R) Software Group Inc. (NASDAQ : JDAS), an international provider of enterprise retail solutions, announced a strategic initiative with IBM to deliver a comprehensive solution for global retailers wanting an accelerated, yet low risk, implementation to support their e-commerce operations. This partnership expands upon an agreement finalised in 1998 between the two companies, which resulted in JDA developing the front-end of MMS.com (TM), the retail industry's first integrated business-to-consumer e-commerce solution, based on IBM's Net.Commerce. The new arrangement bundles complementary services to deliver a well-defined services roadmap, enabling retailers to smoothly transition from e-commerce strategy development through implementation and execution.

[1]Identifying words/phrases are underlined.